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REUSE OF SOLID WASTE FROM WATER-SOFTENING PROCESSES

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Raynor D. Nelson and Eben Vey

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REUSE OF SOLID WASTE
FROM WATER-SOFTENING PROCESSES

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to the Village of Park Forest, Illinois, was written
by RAYNOR D. NELSON *and* EBEN VEY, *IIT Research Institute,*
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1973

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ABSTRACT

A program was conducted to study methods for dewatering a water softening sludge from the Village of Park Forest, Illinois and to evaluate uses for the dewatered sludge or ways in which it can be disposed of.

The initial concentration of the sludge is between 3.6 and 3.9 percent solids by weight. The sludge solids contain about 84 percent calcium carbonate, 11 percent magnesium hydroxide, and 5 percent miscellaneous and have 90 percent of the particles in the 1.5 to 30 micron range.

The sludge is suitable for use as a mineral filler in paints, floor coverings, caulking compounds, and bituminous products. It can be mixed with sands, clays, and organic soils to improve their workability and strength characteristics. It can also be used as an agricultural liming material to improve workability and fertility of soils. If required, it can be used as a filler in concrete without adversely affecting strength and shrinkage characteristics. Almost all of these uses would require the sludge to be in dry powder or almost dry condition.

The best method of dewatering the sludge is vacuum filtration after gravity thickening. In addition to being the most economical of those considered to be employed at Park Forest (vacuum filtration, centrifuging, lagooning, and sand bed drying), the air passages induced in the filter cake accelerates further drying. This would further improve the handling characteristics and enhance the utilization possibility. This dewatering method will produce a filter cake of about 45 percent solids and an almost clear filtrate which can be returned to the plant.

PREFACE

This report covers research conducted for the Village of Park Forest, Illinois by IIT Research Institute (IITRI Project No. D6007). The project was sponsored jointly by the Village of Park Forest and the U.S. Department of Health, Education, and Welfare, Bureau of Solid Waste Management* under a participating Grant No. 1-D01-UI-00142-01. Persons who contributed materially to this work were E. Vey, Project Director; Raynor D. Nelson, Project Engineer; and J. M. Baryla. Mr. R. Kent Anderson was the Project Officer for HEW. Mr. Robert G. Pierce, Village Manager, and Robert Enzweiler, Water Superintendent provided contributions from the Village of Park Forest.

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*Now the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency.

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REUSE OF SOLID WASTE FROM WATER-SOFTENING PROCESSES

I. INTRODUCTION

Lime is used in the water softening process of many communities in the United States for both surface and well water supplies. The lime sludge produced in this process is composed of the spent lime, the products of coagulation and water with a water to solids ratio ranging between 25:1 to 30:1.

For relatively small water plants (less than 20 million gallons per day average consumption) in those areas of the country where natural limestone is abundant resulting in the low cost of lime delivered to the treatment plants, it is economically unfeasible to process the sludge so that it is reusable. In most of these communities the present practice is to dispose of the sludge by lagooning on land located as close to the treatment plant as possible. In the past, this was not a problem for communities where land was readily available for this purpose and where long range prospects did not involve future land use for which the sludge would render it unsuitable. But population statistics in recent years indicate increasing expansion in the vicinity of metropolitan areas at the expense of rural areas.

This is the situation for the Village of Park Forest, Illinois and a number of other communities which are growing in population. This is causing a heavier load on the water supply, more sludge to be generated in the treatment process requiring more land area for lagooning while adjacent land is in greater demand for community expansion.

At the present time, the Village of Park Forest is disposing of their lime sludge into a lagoon on lands acquired some years ago. The present lagoon has been filled to capacity and some other means of disposal has to be found. To this end, the Village of Park Forest engaged the firm of Greeley and Hansen in 1966 to make a study of the problem and, if possible, recommend a solution. The Greeley and Hansen study[1/]* and a previous study by J. O. Osterberg[2/] dealt almost exclusively with methods of dewatering the sludge. The latter report gave results of laboratory consolidation tests and measurements of certain properties of the dewatered material relating to its behavior if used as fill. A centrifuge was recommended for water removal in the Greeley and Hansen study but the sludge would still have to be disposed of by trucking and dumping. At the time Greeley and Hansen submitted their report[1/] to Park Forest, they also contacted the IIT Research Institute and the Village Manager of Park Forest and suggested that the problem might be the subject of a research program before the methods suggested in their report were actually undertaken.

To this end, the Village of Park Forest applied for a grant from the Bureau of Solid Waste Management of the Department of Health, Education, and Welfare to further study the problem. A grant (1-D01-UI-00142-01) was obtained and the Village entered into a contract with the IIT Research Institute to make a study of the problem and suggest a solution.

This report covers the work done under this contract which consisted of the following principal tasks:

1. Reduce the water content of the sludge to a level at which the material can be conveniently handled. Study methods for further reduction so that the residue could be beneficially utilized, the final tolerable water content to depend on the use.

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*Numbers in superscript refer to references listed at the end of the text.

2. Maintain a level of tolerable suspended solids in the effluent so that it can be easily disposed of or utilized within present water pollution control standards.

3. Evaluate uses for the dewatered sludge or ways in which it can be disposed of at a minimum cost and minimum reduction in land use value.

II. SLUDGE FORMATION

The sludge is a product of the chemical precipitation of hardness and chemical coagulation to remove turbidity, bacteria, color, and other finely divided matter.

The chemical precipitation of hardness is accomplished by the excess-lime treatment.[3] This process removes portions of the bicarbonate hardness present in the water as calcium bicarbonate ($Ca(HCO_3)_2$) and magnesium bicarbonate ($Mg(HCO_3)_2$). In removing Ca^{++}, lime converts free CO_2 and bicarbonate ion to normal carbonate ion. A relatively insoluable precipitate of calcium carbonate is formed and is removed by settling. This reaction is given by the equation

$$Ca(HCO_3)_2 + Ca(OH)_2 + H_2O \rightarrow 2CaCO_3 \quad + 3H_2O.$$

To precipitate Mg^{++}, hydroxyl ions must be provided in order to form an insoluble precipitate of magnesium hydroxide, the solubility of magnesium carbonate being relatively high. An excess of 2 to 3 grains per gallon of hydrated lime is required thus accounting for the name "excess-lime" given to this treatment. This reaction is given by the equation

$$Mg(HCO_3)_2 + 2Ca(OH)_2 + H_2O \rightarrow 2CaCO_3 \quad + Mg(OH)_2 \quad + 3H_2O.$$

In order to prevent cementing of filters and incrustation of pipes and to remove unwanted causticity, the water is then recarbonated with CO_2 gas. This also cuts off the precipitation of Ca^{++} and Mg^{++} and stabilizes the water. These reactions are given by the equations

$$CO_2 + CaCO_3 + H_2O \rightarrow Ca(HCO_3)_2, \text{ and}$$

$$CO_2 + Ca(OH)_2 + H_2O \rightarrow CaCO_3 \quad + 2H_2O.$$

Chemical coagulation is accomplished by adding sodium aluminate ($Na_2O \cdot Al_2O_3$) to the water. When both lime and sodium aluminate are added, the following reaction takes place with the calcium aluminate as the coagulant.[4/]

$$Ca(OH)_2 + Na_2Al_2O_4 \rightarrow CaAl_2O_4 + 2NaOH,$$

$$Ca(HCO_3)_2 + 2NaOH \rightarrow CaCO_3 + Na_2CO_3 + 2H_2O, \text{ and}$$

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4.$$

Another coagulating chemical often used is alum which reacts to form an aluminum hydroxide ($Al(OH)_3$) precipitate which acts as a coagulant. Iron salts reacting to form ferric hydroxide ($Fe(OH)_3$) are also sometimes used as coagulating chemicals.

As can be seen from the above processes in water treatment, sludges can vary in composition depending on the amounts and type of chemicals added to remove impurities. The sludge composition may vary as the composition of the intake water varies. This is especially characteristic of treatment plants that obtain their water from rivers. These waters tend to have large and varying amounts of suspended and organic matter when compared to well waters. In general, hydroxide sludges are slimy and are hard to handle and dewater. They also hydrate readily and form relatively large masses of low density. Carbonate sludges are more granular and are easier to settle and dewater.

The water treatment plant of the Village of Park Forest, Illinois uses the excess-lime treatment for softening and sodium aluminate as a coagulating chemical. The raw water is obtained from wells located in the area. A diagram of the plant operation is shown in Fig. 1. The lime and sodium aluminate are added to the raw water after aeration as it enters a clarifier. The clarifier overflow is then carbonated with CO_2 gas and passed

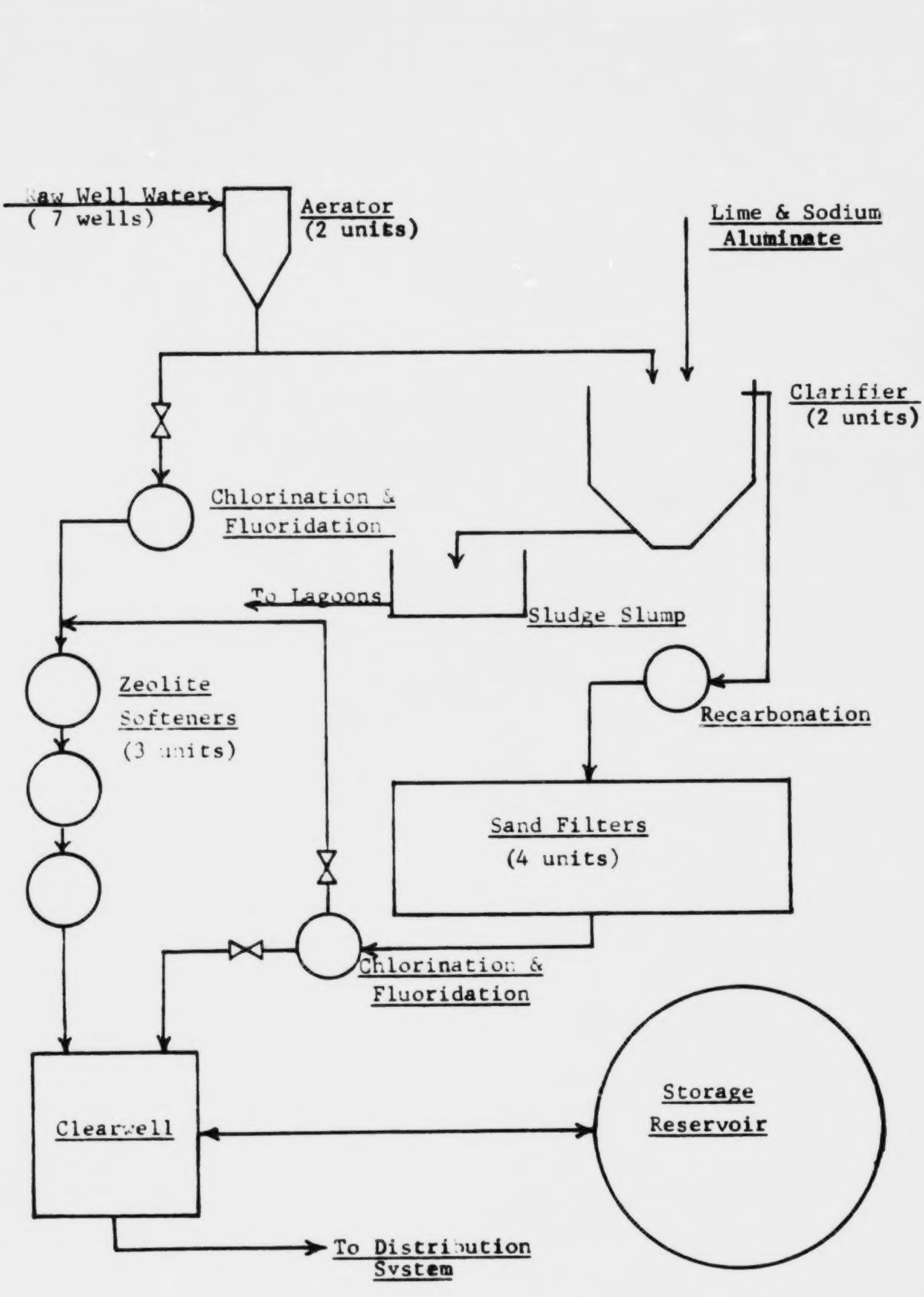
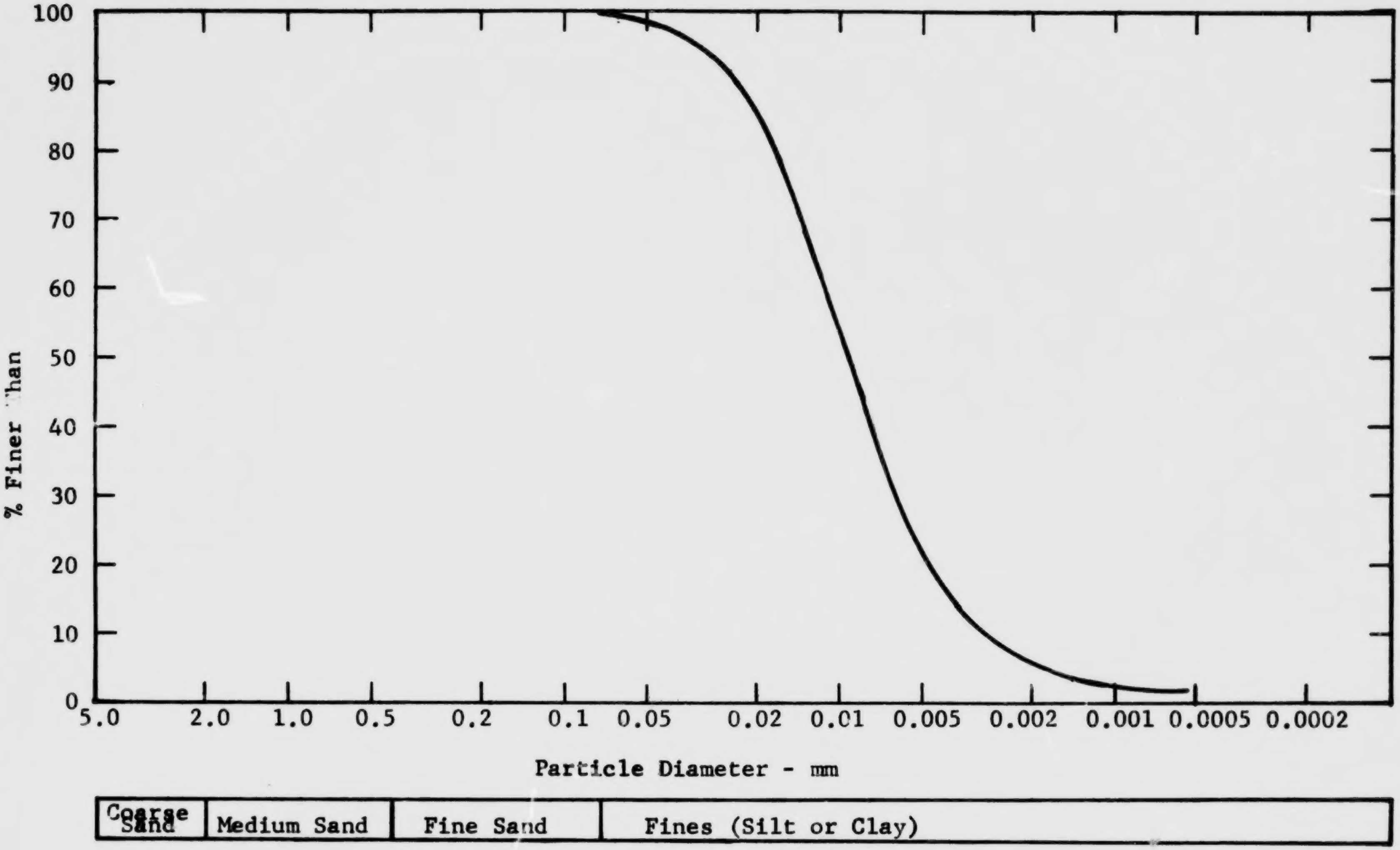

Raw Well Water
(7 wells)
Aerator
(2 units)
Lime & Sodium
Aluminate
Clarifier
(2 units)
Chlorination &
Fluoridation
To Lagoons
Sludge Slump
Zeolite
Softeners
(3 units)
Recarbonation
Sand Filters
(4 units)
Chlorination &
Fluoridation
Clearwell
Storage
Reservoir
To Distribution
System

Figure 1 SCHEMATIC DRAWING OF PARK FOREST WATER PLANT

through sand filters. The water is then chlorinated and fluoridated and sent to the zeolite softeners or to the clear well. The backwash from the filters is returned to the clarifiers, therefore, the sludge removed periodically from the base of the clarifiers contains all of the solid materials removed from the water and/or formed by chemical precipitation. The composition remains relatively constant with time because the raw water from the wells contains very little, if any, organic matter and little suspended matter and is not subject to conditions that may cause the composition to vary as it does in surface water supplies.

The sludge as it comes from the clarifiers has a concentration of 3.6 to 3.9 percent solids by weight. The solid particles have an average specific gravity of 2.66 and a particle size distribution as shown in Fig. 2. The chemical composition of the sludge is 84 percent calcium carbonate, 11 percent magnesium hydroxide and 5 percent miscellaneous material which includes fine sand and compounds of aluminum and iron. The specific gravity and particle size distribution were obtained using ASTM Standard Tests (Ref. 3) for soils. The chemical composition was determined by determining the amounts of calcium and magnesium in the solids and assuming that all of the calcium was present as calcium carbonate and all of the magnesium was present as magnesium hydroxide using standard procedures (Ref. 4).



Unified Soil Classification Soil-Separate Size Limits

Figure 2 PARTICLE SIZE DISTRIBUTION FOR SLUDGE SOLIDS

III. CURRENT PRACTICES

A. SLUDGE DISPOSAL

The methods employed for disposal of softening plant sludge have been:[6 to 11]

1. Direct discharge to surface waters
2. Lagooning
3. Discharge to sanitary sewers
4. Freezing
5. Centrifuging
6. Vacuum filtration
7. Sand bed drying
8. Filter pressing
9. Barging to sea
10. Pipeline transport
11. Process improvement
12. Chemical recovery

These disposal methods are also used on coagulant sludges.

Because the wastes from each treatment plant are different, no specific treatment process will yield the same results. While a variety of treatment methods are available, there may be only one or two methods applicable to a specific location.

1. Discharge to Surface Waters

The discharge of water softening plant waste directly to surface water is the most economical method of disposal. Most large softening plants have been built adjacent to their source of supply of raw water, usually a large river, and it has been very simple to discharge the wastes downstream from the intake. Its primary nuisances have been the production of turbidity and the formation of sludge banks. The sludge consists mainly of inorganic matter which has no biological oxygen demand (BOD) and contributes almost no disagreeable tastes or odors to the water. A number of regulatory agencies are now classifying such sludge disposal as water pollution and are enacting legislation to regulate or prohibit the practice.

2. Lagoons

Discharge of sludge into lagoons has also been a relatively simple and economical method of sludge disposal. This method can offer a long term solution to the problem where sufficient land is available at low cost. However, with continued urban development and population growth, land for lagoons becomes difficult to find. The volume of sludge produced is also increased due to the need for more water and treatment plants to supply the urban communities.

In lagoons where softening sludge settles through ponded water a sludge of 40 percent solids concentration can be expected, however, there are instances where only 20 to 30 percent was obtained. A concentration up to 50 percent has been obtained where the supernatant was allowed to flow off the site without ponding. The supernatant may be returned to the water plant or may be allowed to infiltrate the ground or enter a water course with no detrimental effects. The Sanitary Water Board of the State of Illinois requires that the supernatant meet the following requirements to be discharged to a stream or to a storm sewer system:[12]

1. Free of all settleable and floating solids.
2. Suspended solids content less than 20 mg/1.
2. pH of 6.0 - 10.0.

Odor problems with softening sludge lagoons are rare, and are temporary and minor when they occur.

The capacity of lagoons is dependent upon the physical characteristics of the sludge and the amount of dewatering during impoundment. When the sludge has been dewatered to 50 percent concentration, the lagoon capacity has been about

0.5 to 0.6 acre ft/yr/million gallons/day/100 ppm hardness removed. The depths usually vary from 3 to 10 ft but may be much deeper where a canyon or gully is dammed or when a worked out gravel pit is utilized as a lagoon.

A successful operation of sludge lagoons should be one in which they are divided into several independent ponds or pools so that each section in turn is permitted to dry while others are being filled. Dry and fill lagooning is sometimes used where a disposal of sludge as landfill or other use is available. Two or three lagoons are used for alternate filling, drying, and removal.

Measures are usually required to protect the public from potential nuisance or hazard. The lagoons should be strongly fenced as they are an attraction to children and animals. Mosquito and fly abatement may also be required. The growth of pond weeds and grasses may also have to be controlled.

When the lagoons are completely filled with lime sludge, the next problem is how to reclaim the lagoon land area. In Miami, Florida the low land around the water treatment plant was filled with sludge, covered with a layer of topsoil and seeded with grass. Fills have been made by applying sludge from lagoons without predrying, however, heavy loads could not be placed on the fills for several years. One water treatment plant sold their lagooned lime sludge to a manufacturing plant which used it to neutralize an acid waste which could then be disposed of in the sewer system. In most cases the lagoon dewatered sludge is hauled and dumped at a disposal site such as a sanitary land fill; the dewatered sludge having a volume greatly reduced from that entering the lagoon. The lagooned sludge has also been used on agricultural land.

3. Sanitary Sewer Discharge

Disposal of softening sludge to a sanitary sewer is used in only a small percentage of water softening plants.

The sludge is dense enough to settle and plug sewer lines unless adequate dilution water and high velocities are maintained to keep it moving freely. Hydroxide sludges on the other hand are discharged more often to sanitary sewers and have in some cases been reported to increase the amount of BOD removed from waste waters. For both types of sludge best results are obtained if the sludges are discharged to the sewer averaged over a 24 hour period instead of in a large slug which upsets the biological activity. In most cases the added load of the large volume of softening sludge would over tax present sanitary treatment facilities. However, newer facilities designed to include the water treatment wastes have had satisfactory results.

In Daytona Beach, Florida the lime sludge was discharged to the sewage treatment plant. However, the plant had been designed and built to accommodate the sludge. The addition of the sludge with 15,700 lb of dry solids to the sewage treatment plant designed for 70,000 people removed 45 percent of BOD and 75 percent of the suspended solids. The sewage sludge and water softening lime sludge were removed from the upflow clarifier and dewatered by vacuum filtration.

A project is in the planning stages for Dallas, Texas for lime sludge from the city's Bachman Creek Water Treatment Plant to be used to treat overflows from the sanitary sewer system.

4. Sludge Freezing

The freezing of sludges, either mechanically or naturally, removes the water of hydration. The mechanism involved is thought to be ice crystal buildup as the sludge freezes and water of hydration is drawn out of the floc. When the sludge is then thawed, there are no great forces present to draw this water back into the floc. This method is most effective on the gelatinous alum sludges but should also affect the lime sludges. After freezing the alum sludges become like "coffee grounds". Water works in England, Scotland, Japan and West Germany are successfully using mechanical freezing to reduce alum sludges. A water plant in Denmark uses natural freezing in lagoons. The results of experiments in natural freezing of alum sludge lagoons in Rochester, New York indicate a very marked reduction of sludge solids and a change in character of sludge solids which should permit easy disposal. There are no known instances of freezing of lime sludges other than that which occurs naturally in lagoons. The freezing of lime sludges by mechanical methods would require large installations because the volume of lime sludge is much greater than alum sludges per unit volume of water treated.

5. Centrifuging

Centrifuges have been used in waste water treatment plants to dewater primary and activated sludges with some degree of success. However, they have had very limited use in water treatment plants. Their advantages are low space requirements, process automation and ability to handle either dilute or thickened sludge.

For lime softening sludges the centrifuges are used mostly in recalcining operations to dewater the sludge before burning. The centrifuge is also used in this operation to separate out the calcium carbonate from the other sludge components, especially magnesium hydroxide. With sludges containing relatively large amounts of magnesium hydroxide, the water effluent will contain some of this $Mg(OH)_2$ and if recycled, a magnesium buildup will occur which has to be monitored and corrected.

For lime sludges, it is advantageous to gravity thicken the sludge before dewatering in a centrifuge so that the machine may be sized according to the amount of solids to be processed not the volume of water that must pass through.

A water softening lime sludge at a water plant in Michigan was tested using a truck mounted centrifuge.[13] In these tests the sludge was gravity thickened to about 10 percent solids. The tests were run at 3,000 G's and were conducted with a deep pool to insure the highest degree of solids removed. Under this condition, the residence time of the solids in the centrifuge was at a maximum while the drying beach length was at a minimum. As the feed rate was decreased from 10 to 5.5 gal/min, the recoveries increased from 78 to 93 percent while the cake solids decreased from 57 to 53 percent solids. The recovery of almost all of the solids would require use of anionic flocculants to agglomerate the slower settling fines. As removals approached 90 to 100 percent the cake solids dropped to 45 percent. The cost of flocculants for complete removal of fines was $2 to $4/ton dry solids.

At another Michigan site in which the centrifuge was used for classifying sludge a cake of 55 to 65 percent solids was produced which simultaneously captured 85 to 90 percent of the calcium carbonate and rejected 34 percent of the magnesium hydroxide. This was effected by setting the machine variables to provide a shorter retention of solids in the centrifuge. This forced more of the finer and slower settling magnesium hydroxide particles to be rejected while the larger calcium carbonate solids were captured. The shorter retention period was established by a reduction in pool volume and/or an increase in feed rate. For both of these series of tests the properties of the sludge other than being water softening sludge was not given.

6. Vacuum Filtration

Vacuum filtration equipment is extensively used to dewater waste-water treatment sludges but only recently for water softening wastes. Minot, North Dakota was the first water treatment plant to successfully use a continuously operated belt-type vacuum filter to dewater a water softening sludge.[14] The sludge consisting of 1/3 magnesium and 2/3 calcium is concentrated to about 20 percent solids in a gravity thickener. The thickened sludge is then filtered to produce a filter cake of 45 percent solids which is easily handled. The high submergence filter operates at a rate of 30 lbs dry solids/ft^2/hr at a 2.5 min/rev cycle time.

A similar installation is being used at Boca Raton, Florida.[15] The sludge is thickened to 28 to 32 percent solids and filters at a rate of 60 lb dry solids/ft^2/hr to a cake concentration of 65 to 75 percent solids. Rates as high as 80 to 90 lb dry solids/ft^2/hr have been obtained when the sludge has been allowed to concentrate in the thickener over a weekend. The dewatered sludge is then stockpiled and eventually removed by local residents and highway contractors to be used as a soil stabilizer. The sludge solids from the Boca Raton water plant have the same specific gravity as the sludge from Park Forest, the middle 90 percent of the sludge particles range from 2 to 70 microns whereas the corresponding range for the Park Forest sludge is 1.5 to 30 microns. The Boca Raton water contains little, if any, magnesium hydroxide.

The vacuum filter is also used in one of the processes of producing micron sized limestone, sometimes called "whiting "whiting".[16] In this process, calcium carbonate is precipitated from lime water with carbon dioxide, dewatered on a vacuum filter and then dried.

7. Sand Bed Drying

Sand bed drying has been used to dewater sewage and alum water treatment sludge. The dilute sludge is run onto a sand filter bed to a depth of 1 to 2 ft and the water is allowed to filter downward through the sand. This requires from 70 to 100 hours for an alum sludge with a loading of 0.8 lb solids/sq ft. The bed is then cleaned and reloaded. This method requires multiple beds and large land area and has poor efficiency in cold or rainy climates unless covered.

There are no known instances where this method is used to dewater water softening sludges.

8. Filter Pressing

The filter press is used extensively in the chemical process industries for dewatering sludges. They have been utilized in England in the treatment of coagulated alum sludges, but their use in treatment of these sludges in the U. S. has not been extensive. One plant in England, using a 100 cu ft press, dewaters a pretreated alum sludge with a pressing time of 8 hrs. Another plant uses a press for softening sludge containing some magnesium hydroxide. The pressing time is about one hour.

The filter press has been a batch-type process with a lack of automation. This and short life of filter cloths have been serious objections to their adoption. However, almost fully automated filter presses have been recently used on alum sludges on an experimental basis with good results.

9. Barging to Sea

Barging water treatment sludges to sea may be advantageous where the plant is located on a river, close to the sea. To reduce costs the sludge is thickened before hauling to the disposal site. The Northeast Sewage Treatment Plant at Philadelphia barges its lagoon thickened sludge to sea. Washington, D. C. and Baltimore are carefully studying this as a means of sewage sludge disposal. The water treatment sludge for these cities could also be disposed of in this manner.

10. Pipeline Transport

Pipeline transportation of sludges for long distances to lagoons or to ocean disposal is simple and relatively inexpensive. Asbestos cement pipe of 4 to 6 in. dia is adequate and can be constructed at low cost.

The advantages of pipeline transport are low original cost, low maintenance cost, flexibility in handling plant loads, and combining sludge from more than one operation.

11. Process Modification

In order to simplify sludge disposal problems, a modification or change in water treatment process may be advantageous. In the previous methods, chemicals were sometimes added to the sludge to make it dewater or handle easier.

The Broughton Treatment Plant of the Fylde Water Board, England, revised the design of its plant to incorporate contact reactors in lieu of conventional equipment. In Europe this is the "Contact Reactor Process" and the Permutit "Spiractor Process" in the U. S. The reactor is an inverted cone shaped vertical tank. The raw water and chemicals enter the tank tangentially at the apex, flow spirally upward, and discharge over a weir near the top. The raw water and chemicals mix with a sand catalyst admitted at the top of the tank, and the mixture suspension is maintained by the upward spiraling flow of water. The calcium carbonate plates out on the sand catalyst, forming small hard pellets which grow in size until the vertical flow of water can no longer maintain suspension. The pellets drop to the apex of the tank where they are periodically discharged. It is contended the pellet like sludge will contain only 5 to 10 percent water by weight.

From the sludge handling standpoint, the process is attractive but it is reported to have limitations in application:

- minimum water temperature is 55°F,
- magnesium content of raw water should not exceed 85 ppm (as $CaCO_3$),
- turbidity should not exceed 10 ppm,
- trisodium phosphate must be added to retard and control plating action of calcium carbonate on the sand nuclei,
- the reactors in cold climates must be enclosed in heated structures.

However, it was reported that this process, in use at the Fylde Water Board water plant on an underground water of 250 mg/1 calcium carbonate hardness, works well at temperatures down to 32°F. The normal temperature range of the water is 40° to 60°F. They also did not find the magnesium content to be a limiting factor. The water contains magnesium in the ratio of about two calcium to one magnesium.

In another instance the softer of two possible raw waters was selected to reduce the amount of sludge requiring disposal.

The form in which the lime is added affects the physical nature of the calcium carbonate precipitate. Lime-water tends to produce relatively large crystals, whereas lime-slurry produces a larger proportion in the form of fines. The majority of the large softening plants use the lime slurry.

12. Chemical Recovery

Some of the water treatment plants use processes to reclaim useful chemicals from the sludge. Alum is reclaimed from alum sludges by treatment with sulfuric acid. Lime and carbon dioxide are reclaimed from lime water softening sludge by recalcining.

There are two predominant types of recalciners in present use: the rotary kiln and the fluidized bed reactor. The fluidized bed reactor appears to be gaining favor as indicated by recent installations. It is contended that this system operates more economically, produces less dust, produces a harder lime (CaO) which is less susceptible to air slaking, requires less space, and has a shorter startup and shut down time. Other types are variations of multiple hearth furnaces and flash drying furnaces.

Regardless of the type of recalcining equipment used, each process comprises the same steps:

- Sludge thickening and or blending. In some cases, recarbonation is utilized in this step.
- Dewatering by centrifuge or vacuum filtration.
- Flash drying of dewatered sludge by use of off-gases.
- Recalcining at high temperature: converting calcium carbonate to calcium oxide.
- Product cooling, if required.

The available data on existing recalcining plants is summarized in Table 1. The plant in San Diego, California is no longer in operation because they no longer soften their water. The plant in St. Paul, Minn. is under construction.[17/]

a) Sludge Conditioning

The sludge from water treatment and softening consists primarily of calcium carbonate with hydroxide precipitates of coagulants. But it may also contain hydroxide precipitates of dissolved iron, manganese, aluminum, and magnesium as well as silicates, clay and silt particles, and organic matter.

An excess of hydroxide precipitates in the sludge will cause the recovered lime to become useless due to their buildup during recycling through the plant. Therefore, these must be removed prior to recalcining. This separation is usually accomplished by centrifuging either as a separate classification or during dewatering. Recarbonation of the sludge prior to centrifuging will return the insoluble magnesium hydroxide to soluble magnesium bicarbonate. The magnesium is subsequently removed with the effluent which must be wasted. The effluent usually must also be wasted when tastes, odors, or colors are removed. When build up of minor constituents is not a problem, or where tastes, odors, or colors are not present, the effluent can be returned for reprocessing.

Table 1

RECALCINING PLANTS

Location	Approximate Construction Year	Rated Capacity Product Output tons/day	Type of Dewatering Equipment*	Type of Recalciner**	Heat Requirement mil/Btu/Ton of Output	CO_2 Recovered	Lime Plant Cost $	Water Plant Rated Capacity mgd	Lime Fed lb/mg	Sludge/Lime Ratio
Marshalltown, Iowa	----	4.2	C	FC	9.66	---	----	3.5	-----	----
Pontiac, Mich.	----	---	C	FC	----	---	241,000	10	2,200	2.50
Miami, Fla.	1948	80	C	RK	8.5	Yes	856,000	180	1,800	2.20
Lansing, Mich.	1954	30	C	FB	8.0	---	----	20	2,200	2.27
Salina, Kan.	1957	---	C	FC	----	---	----	---	-----	----
Dayton, Ohio	1960	150	C	RK	9.0	Yes	1,500,000	96	2,140	2.47
San Diego, Calif.	1961	25	C	RK	9.0	---	534,000	---	-----	----
S. D. Warren Co.+	1963	70	VF	FB	7.2	---	----	---	-----	----
Merida, Yucatan	1965	40	C	RK	----	Yes	----	24	-----	----
Ann Arbor, Mich.	1968	24	C	FB	----	---	1,200,000	---	-----	----
Lake Tahoe, Nev.++	1968	10.8	C	MH	7.0	Yes	----	7.5	-----	----
St. Paul, Minnesota"	1969	50	C	FB	8.2	Yes	1,750,000	120""	990	2.40

* C-centrifuge; VF-vacuum filter.
** RK-rotary kiln; FB-fluidized bed; FC-flash calcination; MH-multiple hearth.
+ Paper mill owned by Scott Paper Company.
++ Activated sludge disposal plant.
" Now under construction.
"" Lime recalcining plant designed to accommodate future water treatment plant capacity of 170 mgd.

The Lykken-Estrabrook and Hoover processes can also be utilized to remove magnesium and other impurities from the sludge to be recalcined.[3]

The Lykken-Estabrook is a two stage process in which the entire amount of chemicals required is added to 12 percent of the water to be softened. The sludge thrown down contains some magnesium from the water and is then wasted. The over treated water is then mixed with the remaining 88 percent and lime is then recovered from this sludge.

The Hoover process is also a two stage process. Lime is added in the first stage in an amount proportioned to remove only the calcium. The magnesium is precipitated by lime introduced in the second stage. The sludge from the first stage is recovered, that from the second stage is wasted. When a third or final clarification of the water follows recarbonation, the precipitated calcium carbonate of this stage is also recovered.

b) Sludge Dewatering

The sludge after conditioning to remove any undesirable ingredients is then dewatered using a vacuum filter or centrifuge. As shown in Table 1 the use of the centrifuge predominates because of its dual capability of magnesium classification and dewatering. The sludge is sometimes thickened to reduce the amount of water to be processed. However, for magnesium removal the efficiency is reduced as the solids concentration increases.

c) Flash Drying

After dewatering the sludge is flash dried by injecting it into the stream of hot off-gases from the recalciner. The dried sludge is removed in a cyclone separator and the stack gas is scrubbed of particulate material and discharged to the atmosphere.

d) Recalcining

The dried sludge is fed to rotary kilns entering at the upper end of the long, sloping, rotating kilns. The kilns operate at a temperature of about 2000°F. The calcium oxide (CaO) product may be in a powdered form or irregular pebbles.

The dried sludge is fed to the fluidized bed reactor by an air conveyor system where it is instantly transformed into calcium oxide. The calcium oxide forms around "seeds" of previously calcined and crushed pellets which are also fed into the calciner. The pellet growth is promoted by adding soda ash to the sludge prior to flash drying. The soda ash fuses at the calcining temperature of 1600°F to form a molten nucleus to which the calcium oxide and seed pellets adhere. The pellets grow in size in this manner until they reach a size that cannot remain suspended by the fluidizing velocity of the gases in the calciner. At this point they are discharged from the reactor.

The stack gases contain 15 to 27 percent carbon dioxide (CO_2); the amount depending on the excess air used in fuel combustion. However, most of the CO_2 is liberated when calcium carbonate ($CaCO_3$) is reduced to calcium oxide (CaO). The CO_2 in the stack gas can be recovered to be used to recarbonate the softened water and/or sludge before dewatering.

It has been suggested that the CO_2 be recovered and marketed as dry ice. Liquid CO_2 recovery may also be economically feasible as this product requires less energy than the manufacture of dry ice.

Recalcining plants are purported to be feasible when producing above 20 tons/day of calcium oxide using the fluidized reactor process and 50 tons/day for rotary kilns. Recalcining is not the total answer to the sludge disposal problem as there are still materials which must be disposed of. At St. Paul, Minn. recalcination would reduce sludge disposal volume by 83 percent. Theoretically one pound of quicklime will produce about 2.5 lbs of calcium carbonate sludge which upon recalcining will yield back 2 lbs of quicklime. Actually impurities and less than 100 percent efficiency in the process reduce the amount of quicklime reclaimed. Nevertheless, substantially more is produced than that required to soften water. In some plants the excess lime is sold to recover some of the operating costs or in cities with more than one treatment plant the excess from one of the plants is used to supply other plants which do not recalcine their sludge.

There may be unforseen problems in operating a recalcining plant such as those experienced by Ann Arbor, Michigan.[18/] In putting their plant in operation, they had problems with sludge thickening, startup of operation, and lime slaking. They also found that experienced operators are required to balance operations and to isolate variables in production that might point to impending failures and shut downs. When the decision was made to build a recalcining plant, the estimated cost was $440,000. The estimated cost of the completed plant was $1,200,000 or roughly three times the original estimate.

B. SLUDGE UTILIZATION

There are few recorded instances in which the water softening sludge is utilized as a useful product and not placed or dumped some place to just "get rid of it."[7,8,9/]

In Boca Raton, Florida the dried sludge is being mixed into the natural sands in the area to improve water holding characteristics and to improve soil strength beneath pavements.

Grand Forks , North Dakota attempted to use the lime softening sludge in order to stabilize soil in alleys. Initially, sludge application in the first several blocks was highly successful. The sludge was spread, rototilled in, and allowed to settle with no traffic allowed during this time. Later in the fall when more sludge was spread, an extended period of rainfall occurred. It was necessary to block the alleys for several weeks as the soil became a quagmire.

The lime softening sludge from lagoons in Miami, Florida was used to fill low areas near the water treatment plant. Top soil was added and seeded with grass.

In Lompac, California an article was published in the Los Angeles Times on the availability of their lime softening sludge free of charge for anyone to take. A manufacturer considered the use of the sludge as a paint additive, but found other material was commercially available at a cost lower than that of transporting sludge. Other inquiries were received but no good use for the sludge was developed.

There was one instance where the lagooned lime sludge was sold to a manufacturer to neutralize an acid waste with the neutralized waste then discharged to the sanitary sewer. There are also two recent practical applications of lime sludge. One describes the use of the sludge to remove sulphur dioxide from a hot gas stream and the other describes phosphate removal characteristics of the lime sludge.

Lagooned sludges have been used for agricultural purposes under a government subsidy in the United Kingdom. The pellets produced in the contact reactor softening process of the Fylde Water Board are used for pH correction in the clays of the area. Large dumps are provided to store the pellets so that they may be available for spreading on land at times when they are required.

The Water Department at St. Paul, Minn. at one time almost obtained an agreement with a contractor who proposed to dewater the sludge and use the dry calcium carbonate as a filler in asphaltic concrete.[17/] He quickly abandoned the proposal when he considered the handling problems and the costs of drying the sludge.

In Dallas, Texas the lime sludge is proposed to be used to treat overflows from the sanitary sewer system.

One water plant that previously lagooned its sludge and has installed a recalcining plant plans to reclaim the lagoon land by also recalcining the lagooned sludge. This is now being done at Miami, Florida.

C. CURRENT RESEARCH

There are a number of research projects on water treatment sludges.[7/] Most of these involve alum sludges or sludges other than softening sludges. The following are those projects which could possibly relate to softening sludges.

1. Monsanto Research, FWPCA Contract 14-12-199. A study of the market for phosphates recovered from waste treatment sludges. There may be some application to lime sludges.

2. Rex Chainbelt, FWPCA Contract 14-12-194 and General American Transportation Research Corp., FWPCA Contract 14-12-416. These studies are to develop mathematical models for clarifiers, coagulation, and sedimentation that will apply to equipment design.

3. Rand Corporation of Cleveland, FWPCA Contract 14-12-30 and Bechtel Corporation, FWPCA Contract 14-12-156. These studies involve the pipeline transportation of sewage sludges, dredging soil, water plant wastes, and other wastes.

4. District of Columbia Waste Treatment Plant. The treatment and ultimate disposal of calcium carbonate, aluminum hydroxide, and ferric hydroxide sludges is under study. Sludge thickening, dewatering and reclamation processes are being evaluated.

5. University of Cincinnati. The centrifugation and effects of chemical additives on dewatering characteristics of water treatment sludges.

6. University of Massachusetts. The dewatering characteristics of sludges in lagoons is being studied. The factors affecting dewatering and drying rates are being evaluated to assist in design of land disposal systems.

7. University of Illinois. The thickening and vacuum filtration of alum sludges and the basic mechanisms involved in thickening of softening sludges is being studied.

8. Burgess and Niple for Ohio Department of Public Health. This project involves a study of the criteria for design and operation of facilities for water pollution control from softening plants. Information is being gathered on treatment processes and ultimate disposal techniques.

9. Water Resources Quality Control Committee, Illinois Section of AWWA. This study involves the effects, if any, of wastes produced by water treatment plants on potential or existing water supply sources and other uses of water. Existing methods of water treatment waste disposal, quantities of wastes generated and the chemical, physical, and biological characteristics of the wastes are being investigated.

10. City of Dayton, Ohio. Research is being conducted in conjunction with their recalcining plants on the reduction of magnesium content in the recalcined lime and to develop an economic process for recovery of magnesium.

IV. SLUDGE DEWATERING

The most promising methods available to the Village of Park Forest for dewatering or reclaiming a lime sludge are:

- sand bed drying
- lagooning
- vacuum filtration
- centrifuging
- recalcining

Each of these methods was investigated with respect to sludge type and use and in particular for the conditions at the Village of Park Forest Water Plant. The population and water consumption for the Village are given in Figs. 3 and 4, for the years 1950 to 1969 and estimates are shown through 1980. The estimates shown were based on a previous study and were contained in the Greeley and Hansen report.[1/] The recorded population and water consumption since 1965 have been below the estimated values. An annual average consumption of 3 mgd was used to determine the required capacity of the dewatering systems.

The blow down of the clarifiers at the Park Forest treatment plant is regulated to the amount of lime added to the water so that the sludge has a solids concentration of 3.6 to 3.9 percent. A 3 mgd output would produce 535,000 lb of sludge at 3.7 percent solids having a volume of 8400 cu ft and 19,800 lb dry solids.

A. ANALYSIS OF METHODS

1. Vacuum Filter

The vacuum filter utilizes atmospheric pressure on top by creating a vacuum on the under side of the media thus causing a pressure drop through the media and a speeding up of the filtering process.

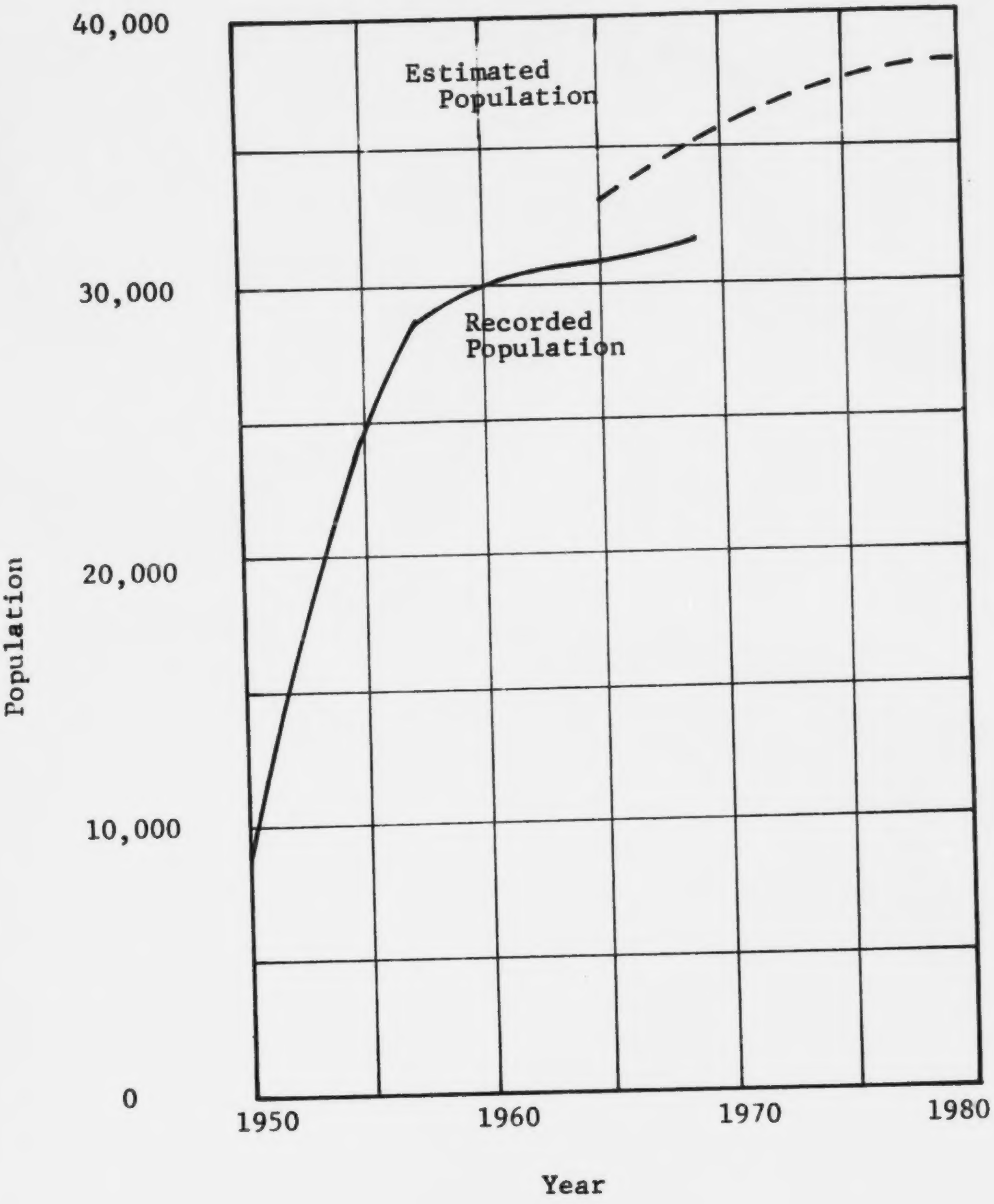


Figure 3 PARK FOREST POPULATION HISTORY

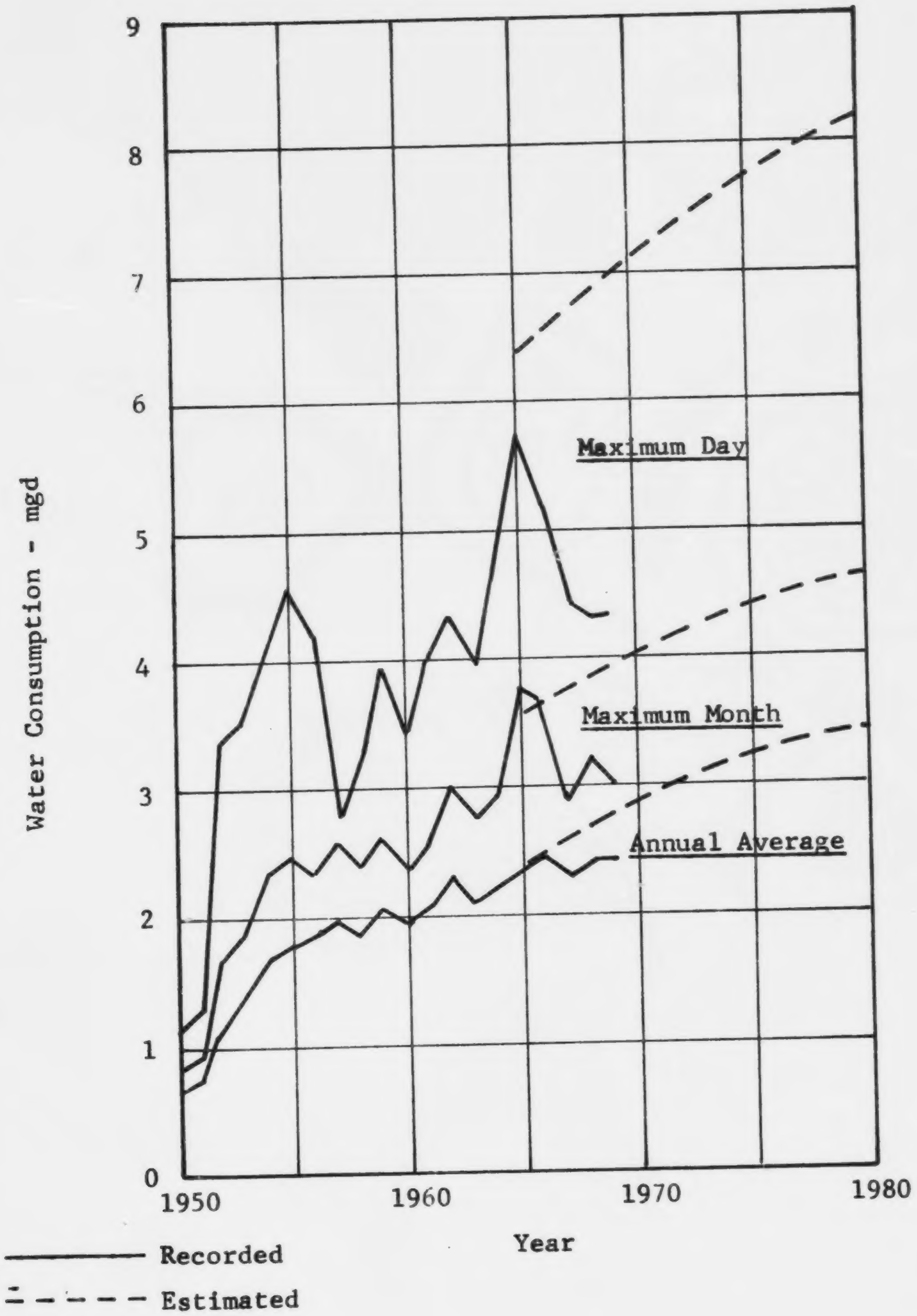


Figure 4 PARK FOREST WATER CONSUMPTION

There are two types of vacuum filters, 1) a bottom loading type drum filter, and 2) a top loading conveyor belt filter.

a) Bottom Loading Vacuum Filter

A bottom loading or drum type vacuum filter incorporates a continuous filter media. It consists of a drum containing a partial vacuum revolving partially submerged in the sludge. During the time a portion of the drum is submerged, the vacuum is causing a filter cake to form on the filter media. When the portion is not submerged, the vacuum is dewatering the filter cake until the position is reached for the cake to be discharged. The amount of water removed can be controlled by the thickness of the cake and time of the drying cycle. These can in turn be controlled by the speed of revolution and vacuum levels.

Because of the settling characteristics of the sludge at low concentrations and the large liquid volume, these units work more effectively when the sludge is somewhat more concentrated than the 4 percent concentration coming from the clarifiers. Therefore, these units require a thickening unit to concentrate the sludge before it is filtered. The thickener would also permit the filter to operate intermittently since the thickener tank can accumulate the sludge produced during a given time period. Intermittent operation would be advantageous for small size plants and those employing only one unit. It would provide time for maintenance and repair and not interfere with plant operation. It also permits latitude in operation to adjust to variations in sludge output due to fluctuations in water demand. The dewatered sludge handling would also be simplified. The sludge could be discharged directly into a truck whereas a more complicated system would be required for a continuously operating filter.

This type of unit is in operation at the water plants at Boca Raton, Florida and at Minot, North Dakota.

b) Top Loading Vacuum Filter

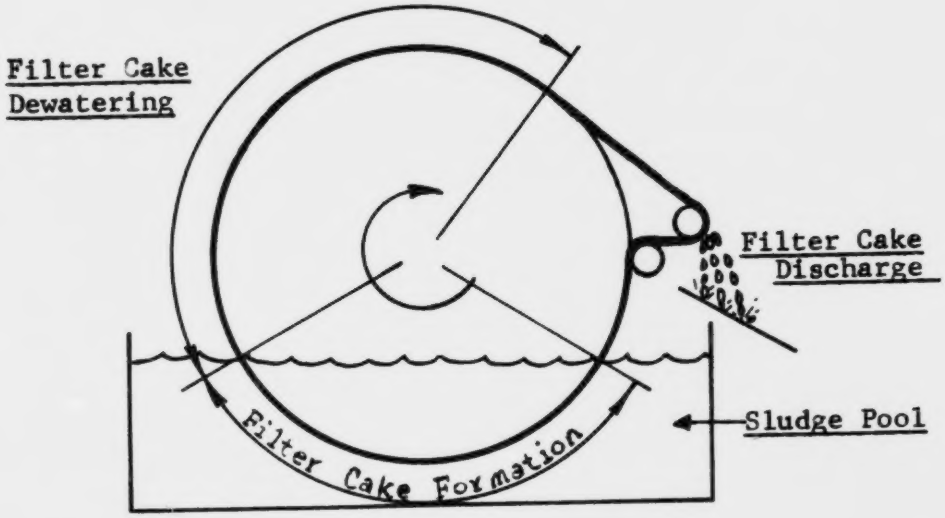
The top loading vacuum filter is a continuous filter media type unit which utilizes the effects of gravity as well as vacuum. The process involves three phases 1) the precoating of the filter media, 2) the formation of the filter cake, and 3) the dewatering of the filter cake. When the filter media first comes into contact with the sludge, a certain percentage of solids passes through the media until enough solids have collected to begin forming a cake. The initial cake then acts as a filter as a thicker cake is formed.

The unit operates by passing the filter media beneath a pool of sludge and then through the air. A vacuum is maintained beneath the filter media. As the media enters the pool and the initial cake or precoat is formed, the water filtered through can be returned to the sludge pool. As the remainder of the cake is formed and the cake dewatered, the reclaimed water can be returned to the plant. The filter cake is formed by the natural gravity settling characteristics of the sludge aided by the applied vacuum.

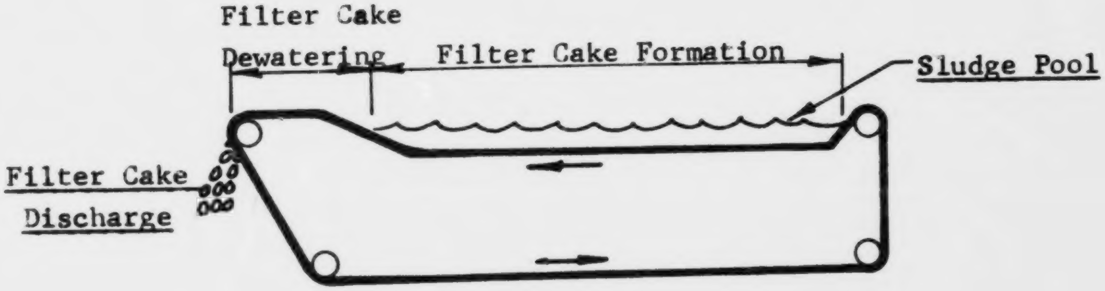
This type unit would not require a thickening unit. The filter media does not have to be as fine as for the bottom loading type unit because after the initial cake is established it becomes the filter media and the initially reclaimed liquid can be returned to the sludge pool. The unit can use either a disposable paper filter media or a continuous reusable media.

Although this type unit has not been used to dewater water softening sludge, it has been used successfully in mill and machine operations to remove mill scale and grindings from coolants which have particles in the same size range as the water softening sludge.

The principal features and modes of operation of each of these filter types are shown in Fig. 5.


Filter Cake Dewatering
Filter Cake Discharge
Sludge Pool
Filter Cake Formation

Bottom Loading Drum Filter


Filter Cake Dewatering
Filter Cake Formation
Sludge Pool
Filter Cake Discharge

Top Loading Filter

Figure 5 VACUUM FILTERS

c) Vacuum Filtration Tests

To better evaluate vacuum filtration characteristics of the sludge and the different types of filters, a series of filter leaf tests were conducted in the laboratory at the IIT Research Institute. Previous experience has shown the filter leaf tests correlated very well with the full scale operation for the Minot, North Dakota water plant.14/

The tests were designed to determine the filter output and dewatered sludge characteristics. The procedure and apparatus used for the tests is described in Appendix I.

The results of the filter leaf tests are summarized in Table 2. The results shown for each set of conditions (filter type, vacuum level, sludge concentration, form cycle time, and dewater cycle time) are average values for many tests conducted with the same or different filter cloths. The dry solids filtration rates are also shown graphically in Fig. 6 and 7.

Filter cloths of nylon, cotton and dynel were used. These cloths were selected from a large group of filter cloths because of their properties and the weave was fine enough to produce a clear filtrate. The test results showed that filtration rates and dewatered sludge properties were independent of the type of filter cloth if the free air flow through the cloth was greater than about 5 cu ft/min/sq ft. When the resistance to free air flow increased, the amount of water removed was decreased. The results reported in Table 2 are only those for the filter cloths with free air flows above 5 cu ft/min/sq ft. It was also observed that the filter cake readily separated from the filter cloth with no apparent blinding of the cloth. For the thicker filter cakes, their weight was sufficient to separate them from the inverted filter cloth; but for the thinner cakes a slight blast of air on the reverse side was needed.

The filter area requirements are based on a 24 hr/day operation for a 3 mgd output and 6600 lb dry solids/mg.

Table 2

VACUUM FILTRATION TEST RESULTS

Filter Type, Vacuum Level and Sludge Concentration	Form Cycle Time (min.)	Dewater Cycle Time (min.)	Dry Solids (lb/ft^2)	Filtrate (ft^3/ft^2)	Dry Solids $(lb/ft^2/hr)$	Filtrate $(ft^3/ft^2/hr)$	Submerged Filter Area Required*		Dewatered Filter Cake			Slope Factor	
							Solids (ft^2)	Filtrate (ft^2)	Moisture Content (%)	Concentration (%)	Thickness (in.)	Solids $(lb/ft^2/hr/min.)$	Filtrate $(ft^3/ft^2/hr/min.)$
Top Loading 3-1/2" Hg 3.9%	5	5	0.59	0.164	7.06	1.97	116.8	154.0	150.8	39.8	0.25	-0.395	-0.630
	10	5	0.89	0.214	5.35	1.28	154.0	238.0	161.3	38.3	0.36		
	15	5	1.17	0.251	4.67	1.00	176.5	305.0	167.5	37.3	0.48		
	20	5	1.41	0.291	4.20	0.88	196.5	347.0	168.5	37.1	0.59		
	25	5	1.47	0.319	3.52	0.77	234.0	395.0	181.5	35.6	0.66		
	30	5	1.71	0.345	3.41	0.69	242.0	442.0	176.0	36.1	0.78		
Top Loading 3-1/2" Hg 9.7%	5	5	0.99	0.119	11.82	1.43	69.8	74.8	157.5	38.8	0.39	-0.495	-0.575
	10	5	1.37	0.159	8.24	0.95	100.0	112.5	164.5	37.8	0.53		
	15	5	1.67	0.190	6.70	0.76	123.0	141.0	174.0	36.5	0.63		
	20	5	1.99	0.218	5.96	0.65	137.5	164.5	183.5	35.3	0.87		
Top Loading 10" Hg 9.7%	5	5	1.14	0.136	13.62	1.63	60.5	65.8	133.8	42.7	0.43	-0.465	-0.435
	10	5	1.70	0.196	10.20	1.17	80.8	91.7	134.0	42.7	0.59		
	15	5	2.10	0.241	8.37	0.96	98.5	111.5	146.5	40.5	0.75		
	20	5	2.38	0.272	7.12	0.91	115.5	118.0	148.0	40.3	0.81		
Bottom Loading 20" Hg 9.7%	1/2	1	0.45	0.055	54.1	6.60	15.3	16.2	123.3	44.9	0.16	-0.491	-0.483
	1/2	1-1/2	0.48	0.062	57.0	7.43	14.5	14.7	124.7	44.5	0.16		
	1/2	2	0.48	0.054	58.2	6.48	14.2	16.7	122.0	45.1	0.16		
	1	1-1/2	0.63	0.088	37.9	5.27	21.7	20.3	128.5	43.7	0.19		
	1	2	0.66	0.083	39.6	4.98	20.8	21.3	123.2	44.7	0.19		
	1	3	0.66	0.084	39.3	5.04	21.0	20.9	121.1	45.3	0.19		
	1-1/2	2	0.78	0.102	31.7	4.08	26.0	26.1	123.4	44.8	0.22		
	1-1/2	3	0.80	0.100	32.0	4.00	25.7	26.7	126.8	44.0	0.22		
	1-1/2	4	0.78	0.103	31.3	4.12	26.4	26.1	123.7	44.8	0.22		
	2	2	0.89	0.116	26.5	3.48	31.1	30.5	125.0	44.5	0.25		
	2	3	0.91	0.117	27.1	3.51	30.4	30.5	122.0	45.0	0.25		
	2	4	0.91	0.118	27.5	3.54	30.0	30.5	122.2	45.0	0.25		
Bottom Loading 20" Hg 17.5%	1/2	2	0.71	0.040	84.9	4.80	9.7	9.9	120.2	45.5	0.19	-0.478	-0.492
	1/2	3	0.71	0.039	85.0	4.67	9.7	10.2	118.2	45.8	0.19		
	1	2	1.03	0.055	61.8	3.30	13.4	14.5	118.9	45.7	0.27		
	1	3	0.99	0.055	59.2	3.30	14.0	14.5	121.4	45.2	0.27		
	1	4	0.99	0.054	59.2	3.24	14.0	14.9	115.3	46.4	0.26		
	1-1/2	2	1.25	0.068	50.0	2.72	16.5	17.6	121.1	45.3	0.36		
	1-1/2	3	1.22	0.070	48.9	2.80	16.9	17.0	123.6	44.8	0.36		
	1-1/2	4	1.10	0.069	44.5	2.76	18.5	17.0	121.3	45.2	0.36		

*Based on 24 hours operation and 19,800 lb dry solids per day.
Filter area equals area of filter submerged in sludge pool.

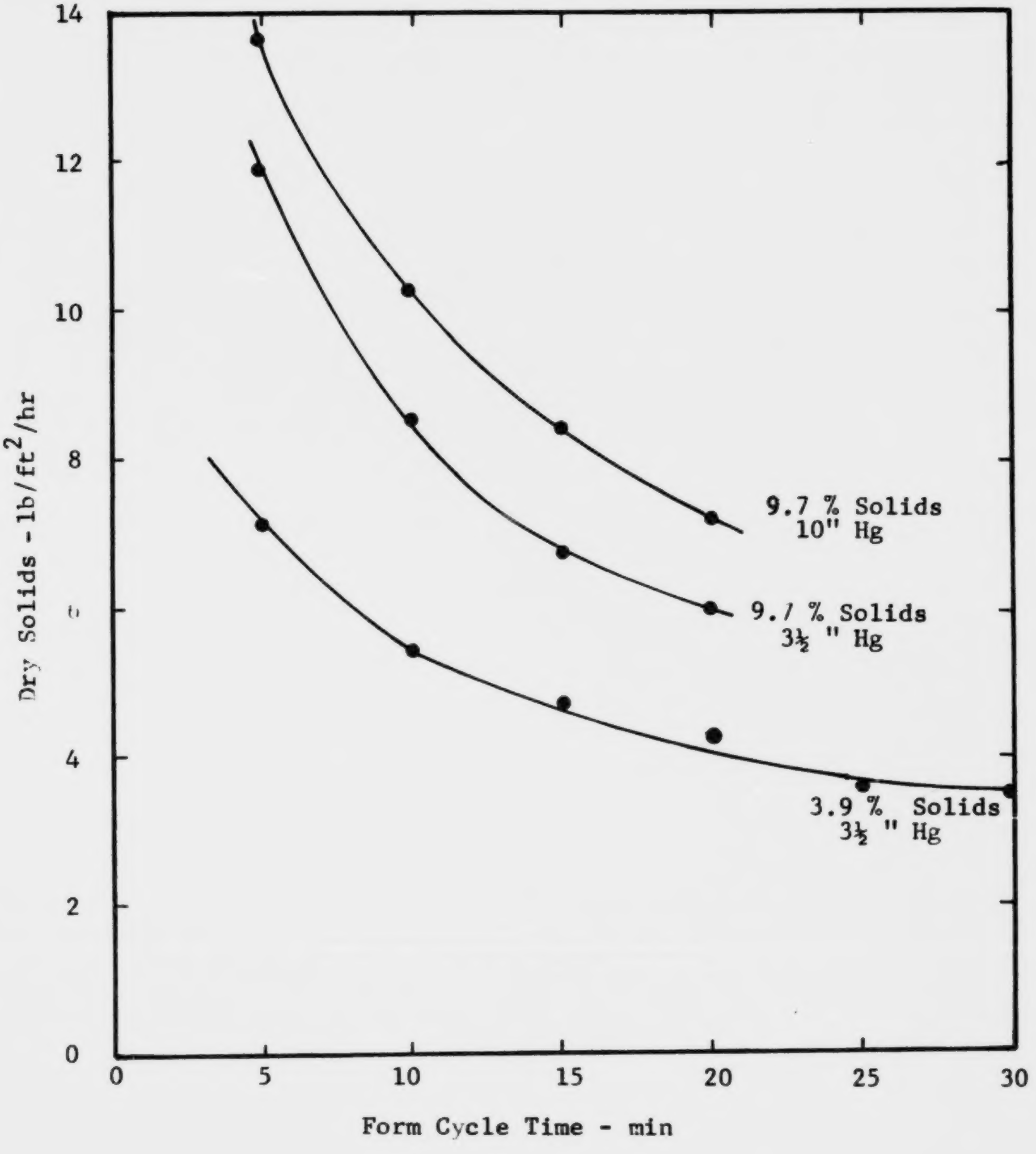


Figure 6 FILTRATION RATES FOR TOP LOADING FILTER

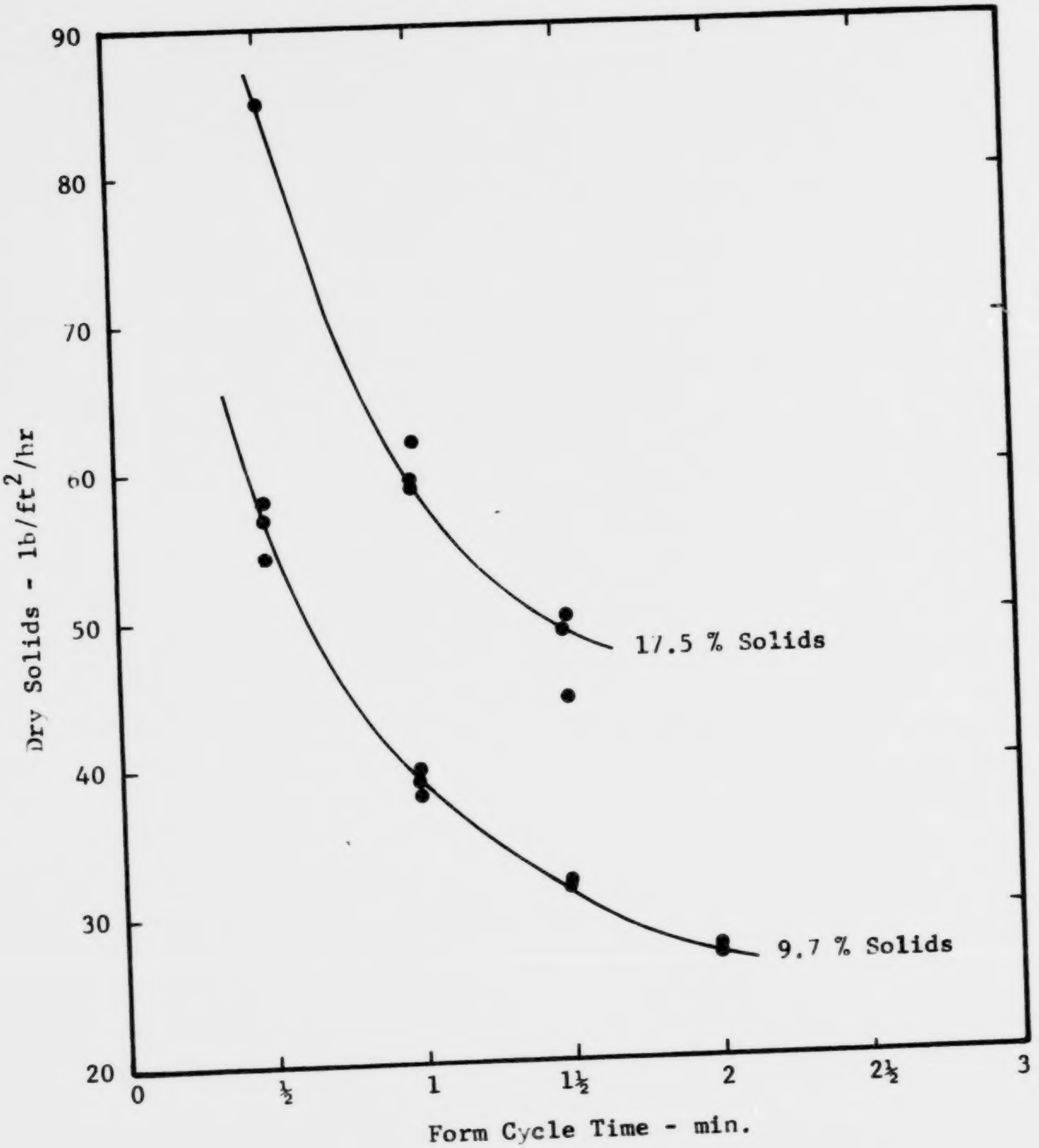


Figure 7 FILTRATION RATES FOR BOTTOM LOADING FILTER

Top Loading Filter. - The results indicate that for an unthickened sludge (concentration - 3.9 percent) the filter cake concentration decreases as the form cycle time and cake thickness increase. The particular machine evaluated is designed for a form cycle time 5 to 10 times greater than the dewater cycle time and a vacuum level of 3-1/2 in. Hg. The results also show that the size of the machine must be based on the amount of filtrate to be obtained.

A second series of tests were performed on the sludge prethickened to 9.7 percent solids. These tests produced a similar filter cake and increased the rates per unit area so that a smaller filter area was required. Prethickening also reduced the filter area required to handle the filtrate to slightly above that required to handle the solids.

Another series of tests were performed on the thickened sludge at a vacuum level of 10 in. Hg. The increased vacuum produced a drier dewatered sludge and also increased the dry solids and filtrate rates. A reduction in filter cake concentration for increased form cycle times was also observed.

For all of these tests a drying cycle time of five minutes was used. This cycle time was used for all form cycles because most of the dewatering occurs at the beginning of the cycle. As the filter cake is dewatered its volume decreases and cracks appear. From this point on, most of the air evacuated to maintain the vacuum level is drawn through the cracks instead of the filter cake and little if any further dewatering takes place. For all of these tests the vacuum level was maintained at the required level throughout the entire cycle.

Bottom Loading Filter. - The results indicate that the bottom loading filter produces a filter cake of the same concentration for form cycle times of 1/2 to 2 min and drying cycle times of 1 to 4 times the form cycle time. This occurred for a sludge concentration of 9.7 percent solids.

A slightly drier cake was formed when the sludge concentration was increased to 17.5 percent solids. The vacuum level was maintained at 20 in. Hg during the form cycle but it dropped to 8 to 10 in. Hg about 30 sec into the dewater cycle when cracks formed in the filter cake.

When the cracks formed and the vacuum level dropped, the air flow through the filter cake increased to about 1 cu ft/min through the cake area of 0.11 sq ft or about 9 cu ft/min/sq ft. For the laboratory tests this was the rated free air capacity for the pumps used in the test setup.

The bottom loading filter produced higher dry solids and filtrate rates and a drier filter cake than the top loading filter. Much of this can be accounted for by the increased vacuum level. The advantage of the top loading filter is the utilization of the gravity settling characteristics of the sludge in forming the filter cake, but the large increase in filter area required to handle the filtrate volume compared to that required to handle the solids demonstrates the advantages of gravity thickening of the sludge prior to filtration. On the thickened sludge, the advantage of the utilization of the gravity settling is lost. The bottom loading method is now definitely superior because the active filter area can be placed on the periphery of a drum, allowing a much smaller unit than the top loading unit. The vacuum level can also be better controlled, especially during dewatering when cracks occur in the filter cake, by dividing the drum into sections and regulating the vacuum level in each section independently. By regulating each section separately a more efficient system can be maintained because of the large differences in air flow required during the form and dewater cycles.

The Poiseuille filtration equation as well as experience have shown the filtration rate to vary inversely with the square root of the cycle time. This says that a log-log plot of filtration rate versus cycle time would have a slope of -0.5. The slope factors shown in Table 2 are quite close to the theoretical value of -0.5 especially for the bottom loading filter. The slope factor was -0.46 for both the filter leaf tests and the full scale operation at the Minot, North Dakota water plant.[14]

To choose a machine size the required operating times to handle the sludge from a 3 mgd output are given in Table 3 for various machine sizes operating at speeds of 2.0, 2.5 and 3.0 min/rev. The sludge concentration is 9.7 percent solids. Based on filtrate volumes, the required operating times should be about 5 to 8 percent greater. If the sludge was prethickened to 17.5 percent solids, the operating times would be 40 to 50 percent less than those shown.

2. Centrifuge

The centrifuge is a machine utilizing centrifugal force to separate suspended matter from liquids. Unlike a filter, there is no physical media to intercept the solids.

The centrifuge works on the principle that when a suspension is rotated at a high speed the heavier particles move to the outside. This applied to water softening sludge would cause the solids to move to the outside and the liquid to remain near the center from where it could be removed. The centrifuge can also be used as a device for separating solids of different material because the mass of particles removed can be controlled by the speed.

The centrifuge used on water softening sludge is a continuous operation type machine with mechanisms to remove the dewatered solids and liquid effluent. For the sludge at 4 percent solids the centrifuge selection would have to be on the basis of the volume of flow to be handled. If a thickener were used the selection could be on the basis of the solids load, and this would permit a smaller unit to be used.

The centrifuge would produce a dewatered sludge of about 40 percent concentration of solids. However, the solids remaining in the reclaimed liquid would consist mainly of magnesium hydroxide ($Mg(OH)_2$) and when its concentration becomes too high the effluent should not be returned to the plant.

Table 3

VACUUM FILTER OPERATING TIME REQUIREMENTS

Design Data

3 million gallons per day water consumption
19,800 lb per day dry solids
30% of filter submerged
9.7% solids sludge concentration

Machine Size Diameter x Width (ft)	Area (ft^2)	Operating Time (hr)		
		2 min./rev	2.5 min./rev	3 min./rev
4-1/2 x 4	56.5	22.9	26.0	28.3
4-1/2 x 6	84.8	15.3	17.3	19.0
4-1/2 x 8	103	12.5	14.2	15.6
6 x 6	113	11.4	13.0	14.2
6 x 8	151	8.5	9.7	10.6
6 x 10	188	6.9	7.8	8.6
8 x 8	201	6.4	7.3	8.0
8 x 10	251	5.2	5.9	6.4
10 x 10	314	4.1	4.7	5.1

Speed	2 min./rev	2.5 min./rev	3 min./rev
Rate	51 $lb/ft^2/hr$	45 $lb/ft^2/hr$	41 $lb/ft^2/hr$

Centrifuge dewatering units are presently being used in some plants particularly where the sludge is recalcined to reclaim lime. In these operations the separation function is utilized to separate out the undesirable magnesium and other compounds from the calcium carbonate ($CaCO_3$).

A sample of the Park Forest sludge was submitted to DeLaval Separator Co. for centrifuge tests. The results showed that the sludge prethickened to 15 percent solids by weight can be dewatered to 40 percent solids by weight with a 40 sec spin time. The tests also showed that 95 percent of the solids were removed and that those remaining were of the soft magnesium hydroxide. The effluent could not be returned to the plant and a treatment or method of disposal would have to be added. These tests illustrate that the principal advantage of the centrifuge method is as a classifier to separate out the magnesium hydroxide from the calcium carbonate.

In selecting a machine size the rates shown in Table 4 were used as a guide. Also shown are the operating times required to handle 19,800 lb dry solids for a 3 mgd output using the lowest rate.

3. Lagoon

The design of a new lagoon was based on the following specifications:

- period of use = 25 years,
- estimated annual average water consumption for the 25 year period = 3 mgd,
- total consumption for 25 year period = 27,400 mg.

The Greeley and Hansen report[1/] prepared for the Village arrived at a requirement of 25.5 acres as follows:

- sludge concentration in lagoon = 30 percent solids,
- sludge solids = 6600 lb/mg
- sludge volume (30 percent solids) = 280 cu ft/mg,
- lagoon depth = 7 ft,

Table 4

CENTRIFUGE OPERATING TIME REQUIREMENTS

Machine Size	Dry Solids lb/hr	Operating Time*** (hr)
14" x 22"*	900	22
18" x 28"**	1000-2000	19.8
24" x 38"*	2000-3000	9.9
32" x 50"**	4000-5000	4.95
40" x 60"**	8000-10,000	2.47

* DeLaval Separator Co.

** Bird Machine Co.

*** Requirement based on 19,800 lb dry solids.

- area = 1,120,000 sq ft = 25.5 acres.

A required area of 22.5 acres was arrived at based on the experience with previous lagoons[7] in which it was found that lagoon capacity was 0.5 to 0.6 acre ft/year/million gallons/day/100 ppm hardness removed. The lime process used at Park Forest reduces the hardness from 550 to 200 ppm or 350 ppm. The required area based on this data is then,

$$\text{lagoon area} = 0.66 \times 25 \text{ yrs} \times 3 \text{ mgd} \times 3.5 \times 10^{2} \text{ ppm}$$
$$= 158 \text{ acre ft} \div 7 \text{ ft depth} = 22.5 \text{ acres.}$$

In order for the lagoon to function properly, the lagoon should be sub-divided and provisions should be made to remove the separated water either to a water course or return it to the plant. An underdrainage system would also increase its efficiency. Further treatment of the separated water would be required to reduce the pH so that it would fall within the required 6.0 to 10.0 range set by the Illinois Sanitary Water Board[12] to discharge it to a water course or storm sewer.

When the lagoon is filled, experience has shown that the sludge has to be removed in order to reclaim the land. The sludge in this state is not suitable as land fill because of the amount of moisture still remaining.

A land area of 40 acres is estimated to be required to provide the required lagoon area.

4. Sand Drying Beds

Laboratory tests were conducted that showed that a sludge initially at 4 percent solids by weight can be dewatered to about 40 percent solids in 24 hrs by allowing a 24 in. thick layer of the material to filter by gravity on a sand layer. This produces a solids loading of 5.12 lb dry solids/sq ft of filter area and a sludge cake thickness of 1.3 to 1.4 in. which would require beds of 3850 sq ft area to dewater the sludge from a 3 mgd output.

A minimum of three beds would be required with a typical schedule of operation for one day as follows:

Bed 1 - being filled with sludge
Bed 2 - sludge dewatering
Bed 3 - dewatered sludge being removed.

These beds would require a large surface area and for climatic conditions in the Chicago region, the beds would have to be protected from rainfall and freezing weather. There also is the probability that when the sludge is removed, some sand will also be removed which may limit the ultimate use of the sludge as well as requiring additional sand to keep the bed functioning. The beds also would require an efficient underdrainage system to provide maximum dewatering.

5. Sludge Thickening

An analysis of the vacuum filtration and centrifuging methods has clearly shown that there are distinct advantages of prethickening the sludge prior to further dewatering regardless of the method used.

Much of the sludge solid material will settle out by gravity if allowed sufficient time. This is evidenced by lagooning and the formation of sludge banks when it is discharged to streams.

It was observed that if the dilute sludge at about 4 percent solids by weight is allowed to stand, a definite demarcation develops between the zone containing suspended particles and a zone of clear liquid.

Figure 8 shows the results of a test in which 1000 ml of sludge at 4 percent solids was permitted to settle. The results show a relationship between the amount of clear water that can be separated from the sludge as a function of time. The concentrating effect decays rapidly with time. After one hour 37 percent of the original volume of sludge could be reclaimed as clear water; after two hours, 54 percent; and after three hours, 62 percent. However, after 72 hours, the clear portion was only 66.8 percent or a concentration of 11 percent solids by weight.

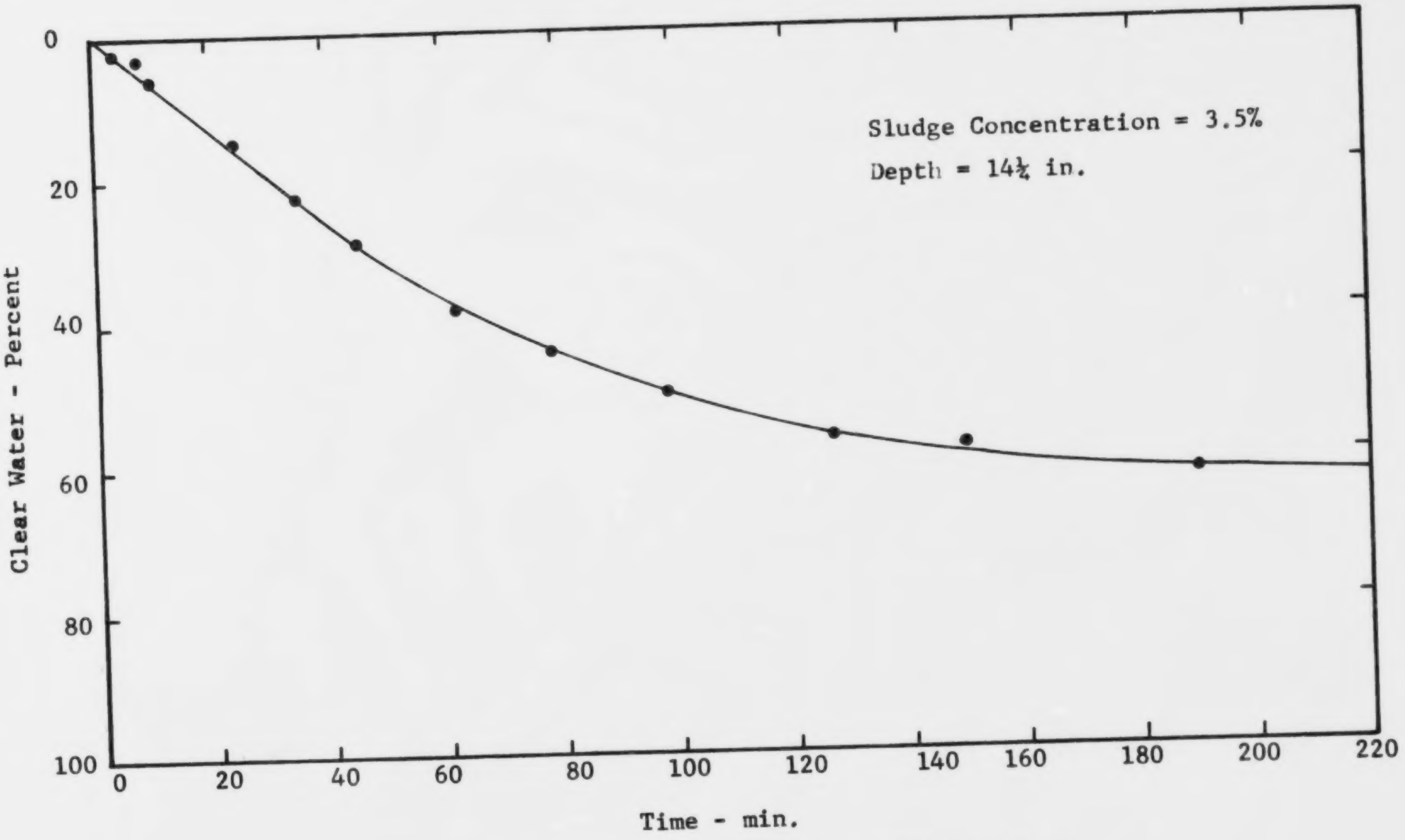


Figure 8 SETTLING CHARACTERISTICS OF WATER SOFTENING SLUDGE

The concentration of the solids in the sludge can be increased by gently stirring the sludge. This breaks up the settled mass and allows drainage channels to develop allowing entrapped water to escape. In process thickening units the stirring is done by vertical pickets attached to slowly rotating radial arms.

At the Boca Raton, Florida treatment plant, the sludge initially at 1 to 4 percent solids was thickened to 28 to 32 percent before applying vacuum filtration.[15/] At the Minot, North Dakota Treatment Plant, the sludge was pre-thickened to 20 percent solids.[14/]

6. Recalcining

Recalcining is a sludge reutilization method that is feasible for some water treatment plants and most likely will become more widely used as the process is refined and updated. For areas where there are large amounts of magnesium in the water, the magnesium components in the sludge must be separated and disposed of, before recalcining can be accomplished. Recalcining does not, therefore, take care of the disposal problem completely. A recalcining operation also becomes a lime producer because more lime can be made from the sludge than initially put into the system. Consequently, an outlet for the extra lime must also be found.

This process would be particularly attractive in areas where limestone products are not readily available and must be shipped long distances. Because of these high shipping costs, lime can be competitive with commercial lime and at the same time produce a marketable product. It is generally accepted that a plant must treat at least 20 million gallons of water per day to justify a recalcining operation.

Recalcining has been ruled out for Park Forest, Illinois because they are situated in "limestone country" and can purchase lime at such a low cost. For example, in January 1969, Boca Raton, Florida was paying about $25/ton for lime compared to $16 for Park Forest. The average consumption of the Park

Forest plant over the next few years is projected to be 3 mgd which is small compared to the criteria for recalcining. The magnesium content of the sludge would also necessitate special operations to remove it prior to recalcining.

Of the methods considered the vacuum filter appears to provide the best means of dewatering the lime sludge. Sand drying beds and the centrifuge method can also produce a sludge cake of about the same concentration. However, during the vacuum filtering process the air drawn through the filter cake forms air passages which enhance further air drying of the cake. The drier the filter cake the easier it is to handle.

B. COST ANALYSIS OF PROPOSED SYSTEMS

To better evaluate the possible dewatering methods an economic analysis was conducted to determine the estimated annual costs for each of four proposed dewatering installations for Park Forest.

The following assumptions were made in preparing the annual cost estimates:

Cost of heated, insulated building	-	$20/sq ft
Cost of protective covers	-	$5/sq ft
Maintenance		
Equipment	-	5% of first cost
Piping and Valves	-	1% of first cost
Buildings	-	2% of first cost
Protective Covers	-	0.5% of first cost
Lagoons and Grounds	-	1.5% of first cost
Salaries	-	$10,000/man yr/5 day week
Power	-	1.1¢/kw hr
Truck Operation (including depreciation, excluding driver)	-	$.30/mi
Value of reclaimed water	-	$.70/1000 gal or 133.3 cu ft
Depreciation on buildings, tanks and piping	-	2% of first cost/yr
Depreciation on equipment, pumps, and lagoons	-	4% of first cost/yr

Depreciation on land - 0

Land costs - $2000/acre

Dewatered sludge can be dumped or disposed of at no cost - 0

Engineering and contingency costs - 25% of first cost

Money can be invested to return 6% interest.

To convert first or fixed costs into annual costs the "straight-line depreciation plus interest on first cost" was used utilizing the depreciation rates given above. To convert the engineering and contingency costs, the lagoon and sand drying beds were assumed to have a 25 year life and the vacuum filter and centrifuge to have a 20 year life.

1. Vacuum Filter with Thickening

The vacuum filter dewatering system proposed includes a 8 ft dia by 10 ft long filter, a 32 ft dia thickening tank, a 70 ft by 90 ft by 6 ft lagoon for emergency overflow, and a truck to haul the dewatered sludge. A heated insulated building must also be provided to house the filter on an elevated stand so that the dewatered sludge can be discharged into a hopper and directly into the truck. The filter would require 6 hr/day operating time at 2.5 min/rev to dewater the sludge produced from 3 million gallons water thickened to 10 percent solids by weight. This was obtained from results of the analysis reported in Table 3. For days of increased consumption the filter can be either operated for a long period of time or at a faster rate. Both the overflow from the thickener and the effluent from the filter can be returned to the water plant. A 70 ft x 90 ft x 6 ft lagoon is provided for emergency purposes. This lagoon can provide space for storage of four days output of dilute sludge or 12 days output of sludge thickened to 10 percent solids from a 3 mgd output. The man power estimates provide for one man to be available 8 hr/day for 7 days/week to oversee the operation, provide maintenance and operate the sludge truck.

The fixed costs are given in Table 5 and the annual costs in Table 6. The costs for the vacuum filter and thickener were

Table 5

FIXED COSTS FOR VACUUM FILTER

Vacuum Filter (8' dia x 10' long)	$ 40,000
Thickening Tank (32' dia)	10,000
Thickening Tank Mechanism	16,000
Building (20' x 32')	12,800
Structure to Elevate Machine	3,000
Truck to Haul Sludge	8,000
Emerging Lagoon	5,000
Piping and Valves	8,500
Pumps	10,500
Sludge Hopper	1,000
Subtotal	$114,800
Engineering and Contingencies	28,700
Total	$143,500

Table 6

TOTAL ANNUAL COSTS FOR SLUDGE DEWATERING SYSTEMS

	Vacuum Filter	Centrifuge	Lagoon	Sand Drying Beds
Annual Fixed Costs	$13,605	$16,275	$28,665	$16,000
Equipment Maintenance	4,000	3,970	280	1,330
Piping and Valve Maintenance	95	95	1,120	185
Tank Maintenance	50	80		
Building Maintenance	315	255		285
Lagoon and Ground Maintenance	75	150	1,000	75
Salaries	14,000	14,000	3,300	28,000
Power	1,200	1,200	500	1,200
Trucking (20 mi/day)	2,200	2,200	0	2,200
Subtotal	$35,540	$38,225	$34,865	$49,275
Allowance for Water Reclaimed	13,800	12,400	0	13,800
Total	$21,740	$25,825	$34,865	$35,475
Total/Ton	$ 6.02	$ 7.17	$ 9.65	$ 9.80
Total/mg	$19.95	$23.65	$32.00	$32.50

obtained from the Eimco Corporation. The piping, valves and pump costs were obtained from the Greeley and Hansen report[1/] with a 10 percent increase.

The total annual cost for a vacuum filter installation with the sludge thickened prior to filtration is $21,740. This includes an allowance for the reclaimed water. The production costs would be $6.02/ton dry solids or $19.95/ million gallons of water treated.

2. Centrifuge with Thickening

A centrifuge dewatering installation would include a 32 in. x 50 in. centrifuge, 32 ft and 20 ft dia thickeners, two lagoons, building and truck. The centrifuge would require 5 hr/day operation to handle the sludge output from a 3 mgd output thickened to 10 percent solids. As compared to the vacuum filter installation a second 20 ft diameter thickening tank and a second lagoon would be needed because the effluent from the centrifuge will contain magnesium hydroxide and cannot be returned to the plant without further settling. The second lagoon would then be used to dispose of the magnesium hydroxide sludge. The building, manpower, accessory equipment and dewatered sludge handling requirements are about the same as for the vacuum filter system. The fixed costs are given in Table 7 and annual costs are given in Table 6. The cost of the centrifuge was obtained from Bird Machine Co.

The total cost for a centrifuge dewatering system is $25,825 which includes an allowance for 90 percent of the water removed being reclaimed. The production costs would be $7.17/ton dry solids and $23.65/million gallons of softened water.

3. New Lagoon

This proposed dewatering method would provide for a new lagoon to be constructed on a 40 acre site to be located 3.5 mi from the water plant. A 25 acre lagoon would be constructed which is estimated to supply the required needs for a 25 yr period. An emergency lagoon is provided at the

Table 7

FIXED COSTS FOR CENTRIFUGE

Centrifuge	$ 40,000
Thickening Tank (1 @ 20' dia and 1 @ 32' dia)	16,000
Thickening Tank Mechanism (2)	28,000
Building (15' x 32')	9,600
Structure to Elevate Machine	3,000
Truck to Haul Sludge	8,000
Lagoon (70' x 90' x 6')	5,000
Emergency Lagoon (70' x 90' x 6')	5,000
Piping and Valves	8,500
Pumps	10,500
Sludge Hopper	1,000
Subtotal	$134,600
Engineering and Contingencies	33,800
Total	$168,400

plant site. The fixed costs are given in Table 8. The costs are the same as those estimated in the Greeley and Hansen report,[1/] and the availability of the same site is assumed to also exist. The total annual cost for the proposed lagoon are summarized in Table 6 with man power requirement being estimated at 1/3 man year for a 5 day week. This method does not provide for the water removed from the sludge to be reclaimed.

The total annual cost for a lagoon at a remote site 3.5 mi from the plant is $34,865. The unit cost would be $9.65/ton dry solids and $32/million gallons of softened water.

4. Sand Drying Beds

The use of sand beds for dewatering the sludge would require three beds of 3800 sq ft each with protection from rain and freezing weather. Equipment and man power were provided so that one of the three beds can be cleaned each day with the dewatered sludge trucked to a disposal site. The estimated man power requirements are two men for 8 hr/day for seven days a week. An emergency lagoon would also be needed. The fixed costs for this method are given in Table 9, and the annual costs are given in Table 6.

The annual cost for sand drying beds is $35,475 which includes an allowance for the water reclaimed. The unit costs would be $9.80/ton dry solids and $32.50/million gallons of softened water.

5. Discussion

Of the four dewatering systems analyzed the vacuum filter is the most economical with an annual cost of $21,740. The next would be the centrifuge system at $25,825 with the added cost being incurred to process and dispose of the effluent from the centrifuge which cannot be returned directly to the water plant as is done in the vacuum filter installation. The construction of a new lagoon has the lowest annual cost if no allowances are made for

Table 8

FIXED COSTS FOR LAGOON

Pumps at Sludge Sump	$ 5,600
Pipe to Lagoon Site (3.5 mi)	117,300
Piping at Lagoon Site	2,500
Land (40 acres)	80,000
Excavation	32,000
Roadway at Site	5,200
Fencing	24,000
Decanting, Influent and Effluent Structures	4,500
Emergency Lagoon (70' x 90' x 6' at Plant Site)	5,000
Subtotal	$276,100
Engineering and Contingencies	66,500
Total	$342,600

Table 9

FIXED COSTS FOR SAND DRYING BEDS

Sand Bed Construction	$ 20,000
Underdrainage System	10,000
Protective Coverings	57,000
Land (2 acres)	4,000
Piping-Valves	8,500
Pumps	10,500
Truck to Haul Sludge	8,000
Sludge Handling Equipment	16,000
Emergency Lagoon	5,000
Subtotal	$139,000
Engineering and Contingencies	34,700
Total	$173,700

reclaimed water. For this method a high first cost is incurred and most of the computed annual cost is the recovery of this first cost making a much smaller portion of the annual cost subject to changes with time such as salaries, machine maintenance and transportation costs. The sand drying beds have the largest annual cost and from an overall standpoint, including the labor required and type of operation, appears to be the least desirable of the proposed methods.

The cost of lagooning the sludge could be reduced if the water decanted could be reclaimed. This coupled with the simplicity of operation could still render this method most advantageous. The lagoon would have the lowest cost if the same land would be available near the plant so that the pipeline required to deliver the sludge to the lagoon would be greatly reduced. However, when the lagoon is full and the land is to be reclaimed the problem of sludge disposal still exists and no allowances in the cost analysis have been made for this purpose.

Therefore, for present conditions as they exist at Park Forest, Illinois the vacuum filter with thickening prior to filtration will dewater the sludge at the lowest annual cost and provide a filter cake with the greatest potential for further drying. The greatest potential for utilization of the sludge would be in the dry or almost dry state. This would also facilitate ease of handling.

The cost of dewatering or reclaiming water softening sludge for various installations is given in Table 10. These costs[9/] are given to show representative costs and should not be compared directly to those prepared and given herein for Park Forest. The costs for Park Forest include the costs for those items not now available and which must be acquired to provide the new facilities. Also included are three plants which recalcine their sludge. These plants have large consumption rates and their unit costs decrease

Table 10

SUMMARY OF COSTS FOR SOFTENING SLUDGE TREATMENT

Facility	Type of Installation	Capacity		Annual Cost	
		Avg.	Max.	$/Ton Solids	$/mg Treated
Boca Raton, Fla.	Thickening (28-30% dry solids) & vacuum filtration	7.6 mgd	23 mgd	16.00	16.00
Dayton, Ohio	Recalcining	60 mgd	120 mgd	6.77 .79*(profit)	29.10 2.20*(profit)
Lansing, Mich.	Recalcining	23 mgd	40 mgd	13.85 3.61**	29.40 7.60**
Miami, Fla.	Recalcining	81 mgd	120 mgd	7.90 2.27***(profit)	13.92 3.95***(profit)
Minot, N.D.	Thickening (20% dry solids) & vacuum filtration	5 mgd	18 mgd	7.29	21.80
Willingboro, N.J.	Lagoons	2.1 mgd	10 mgd	33.50	4.90
Model Study	Thickening (30% dry solids) & vacuum filtration	10 mgd		12.35	12.35
Model Study	Thickening (30% dry solids) & centrifuge	10 mgd		11.40	11.40

*Sale of lime produced at $14/ton and CO_2.

**Sale of lime produced at $17.50/ton.

***Sale of lime produced at $21.13/ton.

as average consumption increases. The installation of a recalcining plant at Park Forest was not considered feasible because of the small size of the plant, the magnesium content of the sludge, and the proximity to large commercial lime producers.

V. SLUDGE UTILIZATION

A second and ultimately more important aspect to the water treatment sludge problem is the disposal of the sludge. Dewatering reclaims most of the water and reduces the total volume to 1/18 of the initial volume which still leaves a substantial amount of material.

Present practice is to lagoon the sludge or discharge it to streams or sanitary sewers and only in a few instances is it utilized constructively such as in recalcining, as a soil additive to improve soil strength and for improving agricultural properties, and to improve sanitary treatment processes. These uses have been reported earlier in the report.

An investigation of possible uses of the material was made to determine if it could be utilized beneficially instead of being disposed of as an unwanted material. Some of the previous attempts to use the sludge reclaimed from lagoons failed because the sludge was not sufficiently dewatered and problems arose in handling and processing because of the excess water. Therefore the dewatering of the sludge to a point where it can be easily handled should enhance the utilization possibilities.

Based on the chemical and physical characteristics of the sludge solids various uses of the sludge were investigated.

As reported previously the sludge solids are composed of mostly calcium carbonate and has a particle size distribution with the middle 90 percent being in the 1.5 to 30 micron range.

The following were investigated as possible uses for the sludge.

1. Mineral filler.
2. Concrete admixture.
3. Soil admixture.
4. Agricultural soil conditioner.
5. Landfill.

A. MINERAL FILLER

An inert mineral filler is used in numerous products. Among the various materials used as mineral fillers are kaolin clay, gypsum, talc, pyrophyllite, mica, diatomite, barite, asbestos fines, silica flour, siliceous rock dusts, portland cement, lime, limestone dust, and micron sized limestone.[16/]

Micron sized limestone, sometimes called "whiting" is used in many different products. Particle sizes range from 1 to 40 microns and it is produced by wet grinding limestone in milky suspensions, dewatering in vacuum filters and/or thickeners and drying in rotary or tunnel driers. It is also produced by precipitating calcium carbonate from lime by addition of carbon dioxide. There are many highly individualized specifications for this material,even for the same apparent use, that it cannot be considered a standard commodity.

The products which consume a major portion of the whiting produced are:

1. White pigment filler and pigment extender in oil or water-soluble paints. Used extensively in cheaper paints, and comprises about 80 percent of the composition of calcimine.
2. Filler in rubber in which it lends reinforcement to the rubber. Used in white side walls of tires. However, the specifications require a minimum of 98 percent calcium carbonates.
3. Linseed oil putty for carpentry and window glazing. This putty consists essentially of 85 percent whiting and 15 percent linseed oil.
4. Paper coating and as a filler with adhesive agents like starch and resin to fill the voids between the fine intermeshed fibers of cellulose. The filler comprises between 8 and 30 percent of the paper weight exclusive of any coating.
5. Mineral filler for floor-covering materials such as asphalt tile, linoleum, vinyl and vinyl-asbestos tiles, and the print paint for printed felt flooring. Asphalt tile contains whiting up to 60 percent of its weight. Linoleum contains 33 to 40 percent. Extreme fineness is a requisite with 99 percent less than 43 microns.
6. Dentrifrices and alkalizers as digestive aids and medicinals. Since U.S.P. products are required, precipitated calcium carbonate is used because higher average purity can be obtained.

The following are some other products which also use whiting, but the total amount used is small compared to that used in the above products.

1. Caulking compounds.
2. Phonograph records.
3. Crayons.
4. Baking powder.
5. Picture frame moldings.
6. Abrasives.
7. White shoe polish.
8. Explosives.
9. Foundary compounds.
10. White ink.
11. Wire insulation coatings.
12. Glue.
13. Greases.
14. Special fabrics.
15. Chewing gum.
16. Leather goods.
17. Asphalt roofing material.
18. Plastics.
19. Pesticides.

In some of the second group of products, the latter three in particular, the use of whiting is very minor as compared to other mineral fillers.

The sludge has the particle sizes in the same range as that of the micron sized limestone. However, it does not have the purity that the commercially processed product possesses. The limestone used in the U. S. for commercial lime and micron sized limestone contains 95 to 99 percent carbonates (calcium and magnesium) with most having greater than 96 percent and more than half in the 97 to 99 percent carbonate range. The sludge contains only about 84 percent calcium carbonate which does not match the purity of the commercial product, but still may be suitable for use in some of the products.

In almost all of the situations where a mineral filler is used it is required that it be in a dry powder form which would require further drying after dewatering and possibly pulverizing to break-up lumps.

From the first group of products, companies with plants near Park Forest were contacted about the potential use of the sludge in their manufacturing processes. From this list, rubber products, dentrifices and alkalizer digestive aids were rejected because of purity requirements. Paper products was also not investigated because only finished products are produced in this area from paper stock produced elsewhere.

The use of the sludge in paint products was explored with the Standard T Chemical Co. in Chicago Heights, Ill. which manufactures paints and similar products for Montgomery Ward Co. They stated that the material was too coarse to be used as a filler in enamels but they were willing to try it as an epoxy filler and in exterior stains and paints. They requested a sample of the material for analysis and their findings to date have indicated that is is not suitable as an epoxy filler because it is moisture absorbent. They are still interested in its use and are investigating its suitability as a filler in latex base systems.

The Flintkote Co. Flooring and Adhesives Division in Chicago Heights was contacted about the use of sludge in flooring tile. Their chemist stated that the material probably could be used as a filler but that they would require the material to be bagged in a dry powder condition. Information on the sludge material was also sent to the company's Research Division which investigates the materials used for their products. No reply has been received to date.

The use of the sludge as a filler in putty was rejected because the magnesium content would cause the putty to harden. However, there is a possibility that it may be used in caulking compounds.

The use of the sludge as a filler in glue was also rejected because its high specific gravity (2.66) would cause it to settle out of a liquid suspension.

Some of the other products may be able to utilize the sludge but could not use a large enough portion of the 10 tons of dry solids produced during a three million gallon day.

Another large user of mineral fillers is the asphalt and bituminous paving materials and products. The ASTM specifications for a mineral filler for sheet asphalt and bituminous concrete pavements state that "The mineral filler shall consist of limestone dust, portland cement, or other suitable mineral matter. It shall be thoroughly dry and free of lumps consisting of aggregations of fine particles."[5/] It is also required that 70 to 100 percent pass the No. 200 sieve (74 microns). The sludge satisfies these specifications and therefore should be suitable as a mineral filler for these products. A bituminous paving concrete required about 2 percent by weight of filler material and could possibly use large amounts of the sludge.

The City of Chicago, Department of Streets and Sanitation, requires a filler to be used in crack and joint sealers that has 100 percent passing the No. 200 sieve and not less than 95 percent passing the No. 300 (50 microns). The sludge also satisfies these specifications. This product requires about 15 to 20 percent filler by weight.

B. CONCRETE ADMIXTURE

Finely powdered admixtures are added to concrete when an aggregate is deficient in fines or when the concrete has a marked tendency to bleed (a settling out of the solid particles).[19/] These admixtures are also used to improve pumping characteristics and to decrease permeability by reducing air content.

The powdered admixtures generally used are pumicite, hydrated lime, diatomaceous earth, bentonite, and flyash. Experience has shown that these materials tend to increase drying shrinkage while they improve workability and there use in large quantities generally tends to require a higher water-cement ratio which may cause some adverse effect on strength and drying shrinkage.

To investigate the effects of the sludge solids on shrinkage and strength characteristics of concrete, trial mixes were prepared using one part type I portland cement and 2.75 parts standard sand for the control mix and 1 part cement, 2.5 parts sand and 0.25 parts sludge solids as the test mix. These proportions were then mixed with sufficient water to produce a flow of 100 to 115 percent. Each mix was then molded into 1 in. x 1 in. x 10 in. shrinkage bars and 2 in. cubes for compression tests. The proportions of sludge solids used in the tests mix was the same as that prescribed in ASTM for testing fly ash for use as an admixture in portland cement concrete (C311-57T).[5/] The compressive strength and shrinkage parts of the specifications (ASTM Desig. C350-57T) for the acceptance of the flyash specify that the compressive strength at 7 to 28 days of the mix with fly ash be 100 percent of the control mix and that the shrinkage at 28 days be less than 0.1 percent.

The results showed that the mix with the sludge required 2.5 percent (57.5 compared to 55.0 percent) more water to produce identical flows of 108 percent with the amount of water expressed as a percentage of the cement weight. Each mix was prepared and tested using procedures specified by ASTM. The seven day compressive strengths were 3 percent higher for the mix with sludge, but at 28 days the strengths were 2.5 percent less than the control mix. Although the shrinkage was 0.126 percent for the mix with sludge it was identical to the control mix without sludge.

These results indicate that the sludge may be used in concrete without adversely affecting the shrinkage and compressive strength parameters. The use of the sludge in concrete would be for a special type of concrete and does not appear to be a very promising method for utilization of the total amount of material produced.

C. SOIL ADMIXTURE

Lime has been used in many instances to stabilize or improve the structural properties of soil.[20,21,22] Lime reacts chemically with soils in two different ways.[20] First, it agglomerates the fine clay particles into coarse, friable particles through the base exchange phenomena. Secondly it produces a "cementing" action in which the lime reacts chemically with silica and alumina from the soil or with pozzolan additives forming calcium silicates and aluminates.

Lime changes the physical characteristics of most clay soils in the following manner.

1. The plastic index drops sharply - sometimes as much as three or more fold.
2. The plastic limit generally increases and the liquid limit decreases.
3. The soil binder (fines) content decreases.
4. The lineal shrinkage and swell decrease.
5. Lime and water accelerate disintegration or breaking up of clay clods during pulverization. Soils become friable and can be worked easily.
6. Unconfined compressive strength increases in some instances as much as 40 fold.
7. Load bearing values, as measured by California Bearing Ratio (CBR), increase.
8. In swampy areas or in soil with moisture contents over optimum, lime application facilitates drying of the soil.
9. A lime stabilized base or subbase forms a water resistant barrier by stopping penetration of surface water or rapid evaporation of existing moisture. It thus sheds water during rains, thereby reducing construction delays.

A series of tests were performed to determine what effects the softening sludge has on soil properties when used as a soil additive. The sludge, because it consists mainly of calcium carbonate and magnesium hydroxide, is relatively inert and does not have the chemical reaction properties that lime possesses which is calcium oxide in its pebble form or calcium hydroxide in its hydrated form.

The water softening sludge from the Boca Raton, Florida plant is being used locally as a soil additive in road building after being dewatered on a vacuum filter. The sludge has been used for flexible pavement road building and is mixed into lawns and other soil areas to increase mobility and decrease permeability or increase water retention characteristics. For stabilizing the subgrade beneath flexible pavements, about 4 in. of sludge is mixed into the top 12 in. of subgrade. The elevation of the subgrade remains the same which means that the sludge materials fill the voids in the sand but do not increase the overall volume. The result is an increase in the Florida Bearing test value from 20 psi (maximum for the sand without sludge) to 70 psi which is the value required by the Florida Highway Department.[23/]

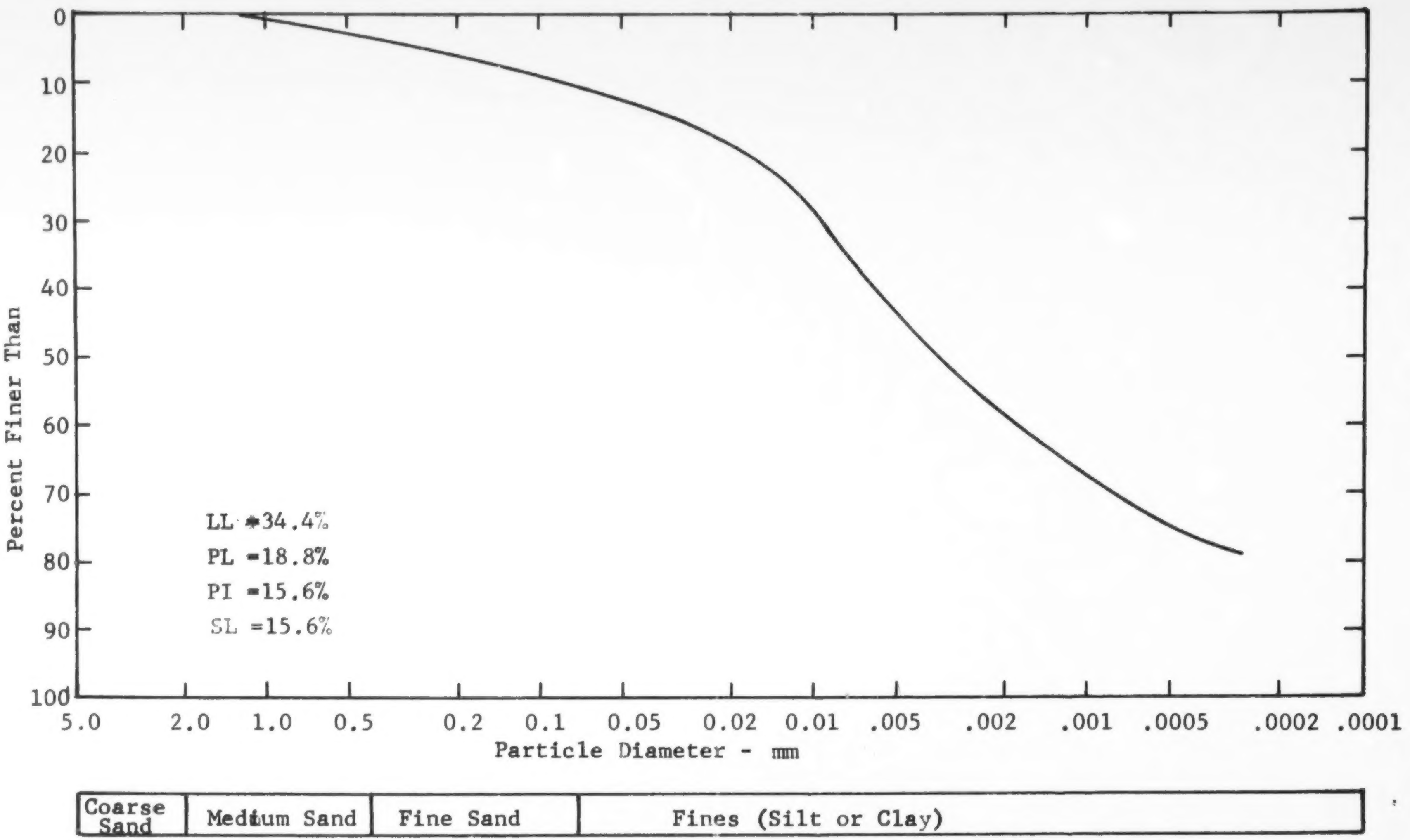
The sludge from the Boca Raton plant is larger in particle size with the middle 90 percent in the 2 to 70 micron range compared to the 1.5 to 30 micron range for the Park Forest sludge. The Boca Raton sludge contains less magnesium hydroxide and more iron compounds because iron is also removed from the water during the treatment process.

A series of tests were conducted with different proportions of sludge to determine what effects the sludge would have on the soil properties. The soils used were a clay which will be designated Park Forest clay and an organic soil both obtained from within the Village of Park Forest, another clay which will be designated Chicago clay and a sand which will be designated Lake Calumet sand. The Chicago clay was chosen because it is found underlying a large part of the Chicago area and when removed is often discarded as a material unsuitable for fill. The sand was chosen because of the success reported at Boca Raton on sand. The sand was obtained from a job site on Lake Calumet at the southwest end of Lake Michigan and is typical of sand found in the general area.

1. Park Forest Clay

The Park Forest clay is a glacial clay and is classified as A-6 in the AASHO and CL in the Unified Soil Classification Systems.[24] The grain size and Atterberg limits are shown in Fig. 9. The moisture content of the soil as it was removed from the ground was 16.8 percent which is below the plastic limit. The soil was obtained from an area near the present sludge lagoons where some of the soil had previously been removed and used for fill material.

The effects of 10, 20 and 30 percent proportions of sludge on the properties is summarized in Table 11. The proportion of sludge is expressed as a percentage of sludge compared to the natural soil. The added sludge causes the plastic limit to increase but does not affect the liquid limit. This results in a lower plasticity index. The shrinkage limit increased when sludge was added. The compaction characteristics remained about the same for the standard test with a slight decrease in maximum density and a slight increase in optimum moisture content when sludge was added. For the modified compaction test the maximum density decreased about 5 percent over the range of 0 to 30 percent sludge and the optimum moisture content increased. These results are shown in Fig. 10-11. There would be an expected decrease in dry density because the sludge has a lower specific gravity and consequently would produce a lower average specific gravity of the total solids. However, the observed decreases are greater than that which can be accounted for by the reduction in specific gravity.



Unified Soil Classification Soil-Separate Size Limits

Figure 9 PARTICLE SIZE DISTRIBUTION FOR PARK FOREST CLAY

Table 11

SUMMARY OF TEST RESULTS FOR PARK FOREST CLAY

		Atterberg Limits				Standard Compaction					Modified Compaction					Classification		
Sludge Percentage	Specific Gravity	Liquid Limit %	Plastic Limit, %	Plasticity Index, %	Shrinkage Limit, %	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Swell, %	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Swell, %	Group Index	AASHO	Unified
0	2.756	34.4	18.8	15.6	15.6	15.6	115.6	10.8	7.3	0.63	12.1	126.3	41.4	16.8	0.66	10.2	A-6	CL
10	2.747	34.4	20.3	14.1	18.4	15.4	115.0	13.3	7.5	0.74	13.0	125.0	38.0	17.9	2.88	9.7	A-6	CL
20	2.740	34.0	21.8	12.2	21.5	16.2	114.3	11.1	4.9	1.42	13.5	122.9	38.5	24.6	1.92	9.2	A-6	CL
30	2.734	34.8	21.2	13.6	23.2	15.9	113.9	18.0	8.9	0.92	15.4	120.0	30.3	9.8	0.31	9.4	A-6	CL

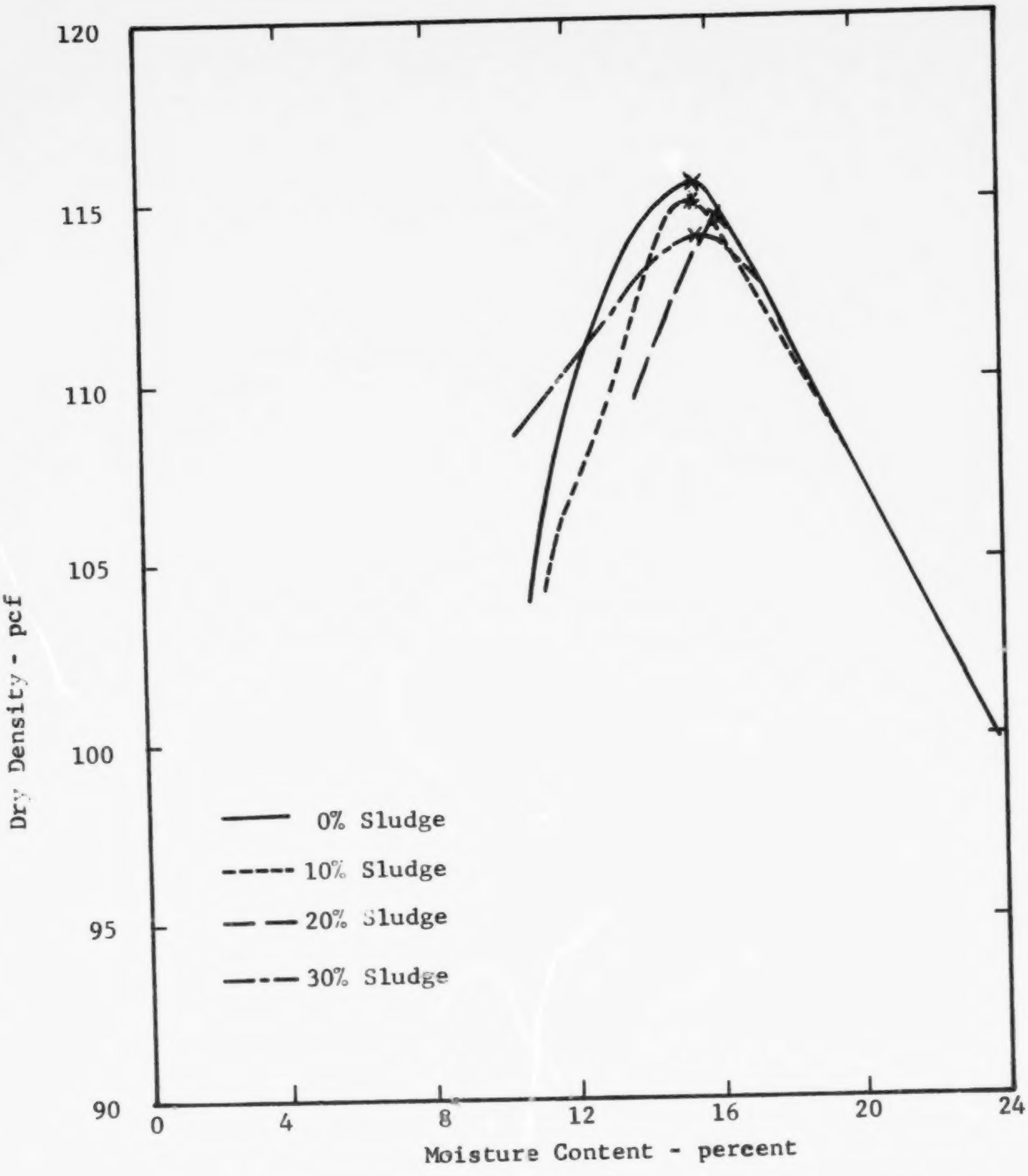


Figure 10 STANDARD COMPACTION CURVE FOR PARK FOREST CLAY

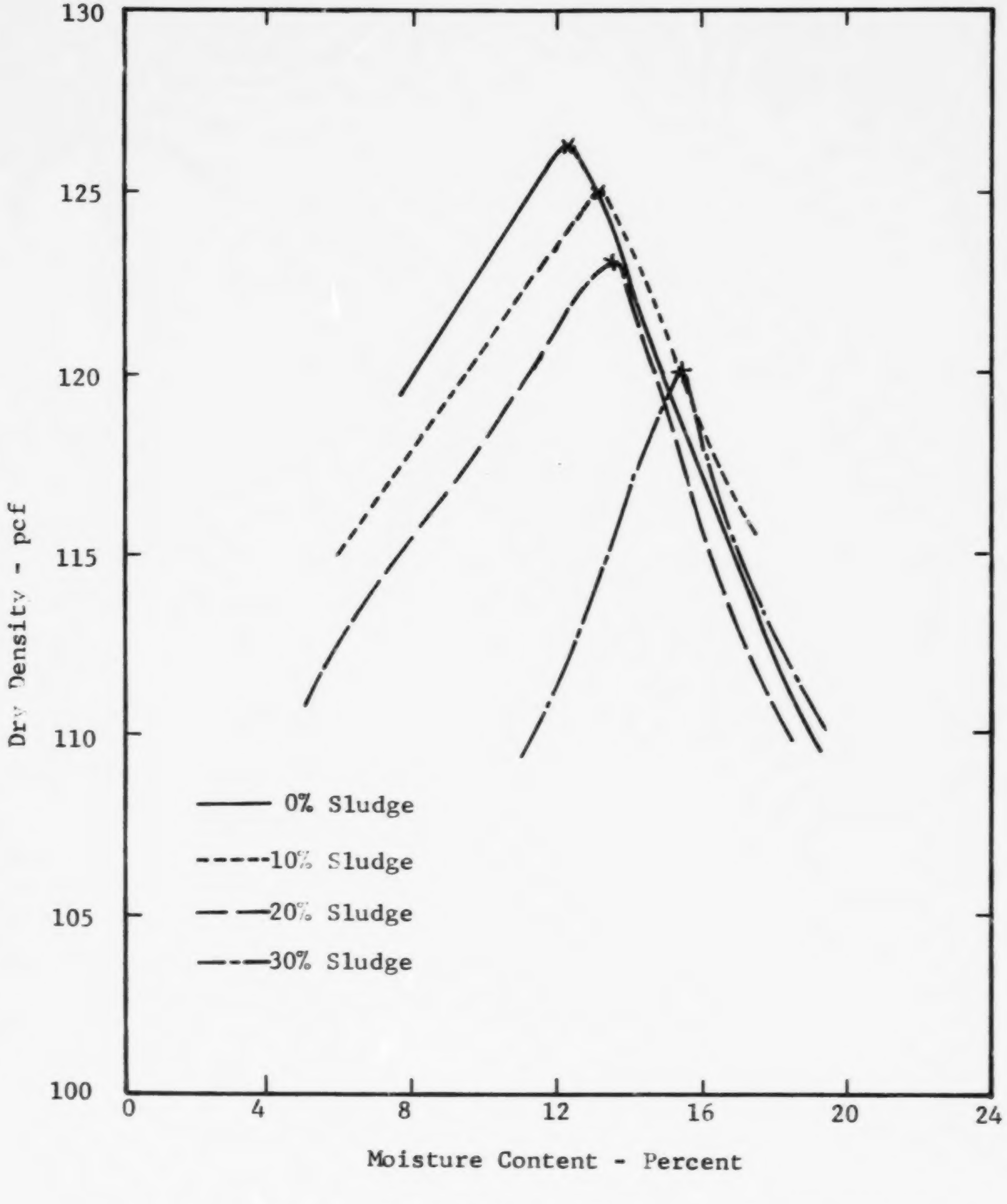


Figure 11 MODIFIED COMPACTION CURVES FOR PARK FOREST CLAY

The effects of the sludge on the strength properties were determined by measuring the CBR. These tests were conducted on specimens compacted to optimum conditions as determined by the standard and modified compaction tests. The results (Fig. 12) indicate that the added sludge increases the CBR for specimens at standard compaction optimums. The results are less pronounced for the soaked specimens with a decrease being observed at 20 percent sludge. The added sludge resulted in decreased CBR for specimens compacted at modified optimums for unsoaked specimens whereas an increase was observed for soaked specimens up to 20 percent sludge.

During all of the tests it was observed that the sludge increased the workability and made it much easier to mix the soil with water to obtain the required moisture conditions.

In summary, for Park Forest clay, the added sludge increases the workability of the soil which is expressed by a reduction in the plasticity index. The CBR increases at lower compactive efforts and decreases at high effort, however, for soaked conditions the CBR is almost constant for low effort and increases for the higher compactive effort. The added sludge causes the volume change due to soaking the soil to increase and shrinkage due to drying the soil to decrease. The optimum dry density decreased and the optimum moisture content increased for both low and high compactive efforts with the differences in maximum dry density being greater at the higher compactive effort. The sludge did not change those properties used to classify the soil enough to change its classification in the AASHO or Unified Soil Classification Systems.

2. Chicago Clay

The Chicago clay is classified as A-6 in the AASHO and CL in the Unified Soil Classification Systems. The grain size and Atterberg limits are shown in Fig. 13. The soil contains about 10 percent coarse sand and gravel (particle size > 1 mm). If this material is disregarded the remaining

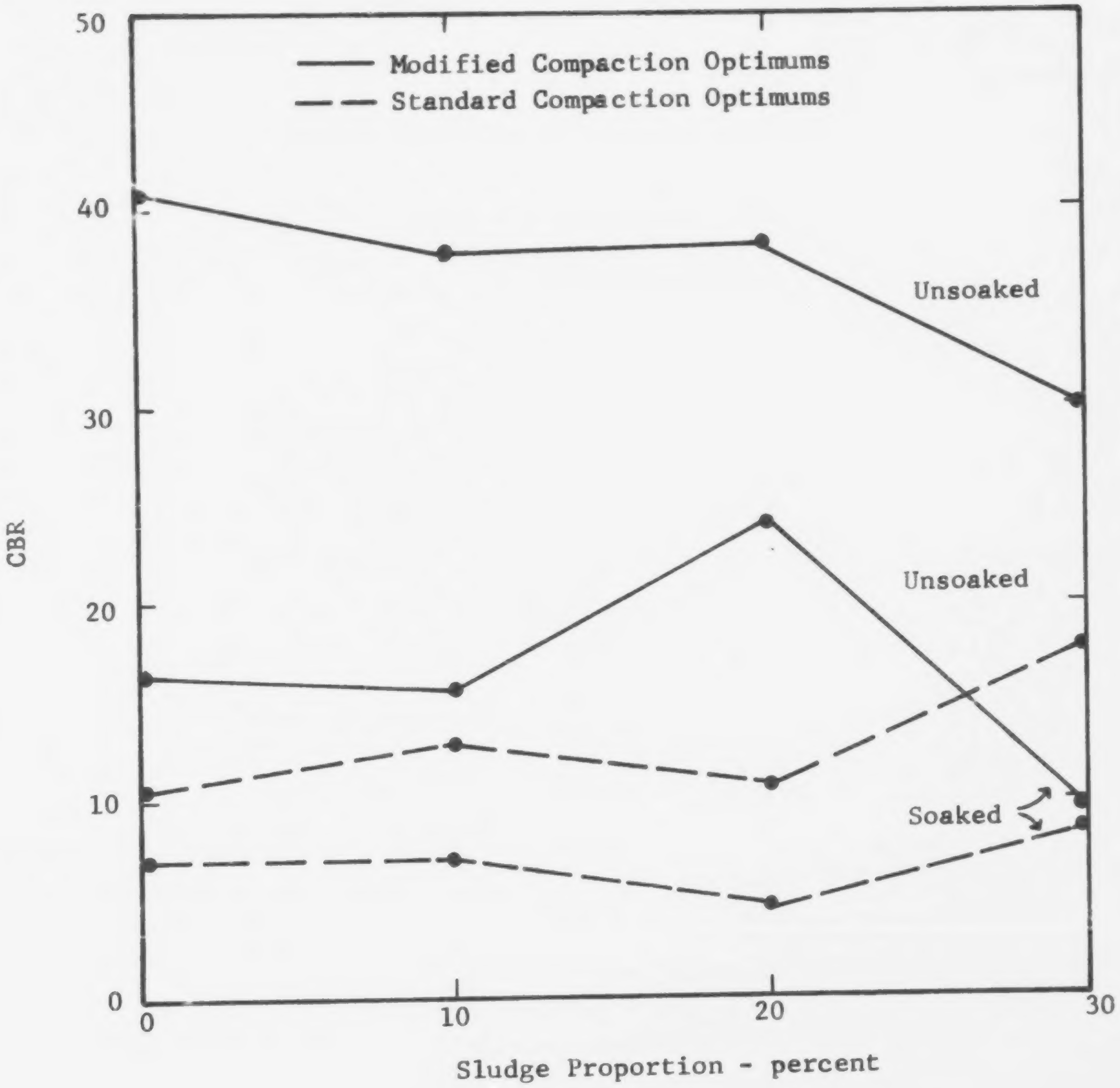
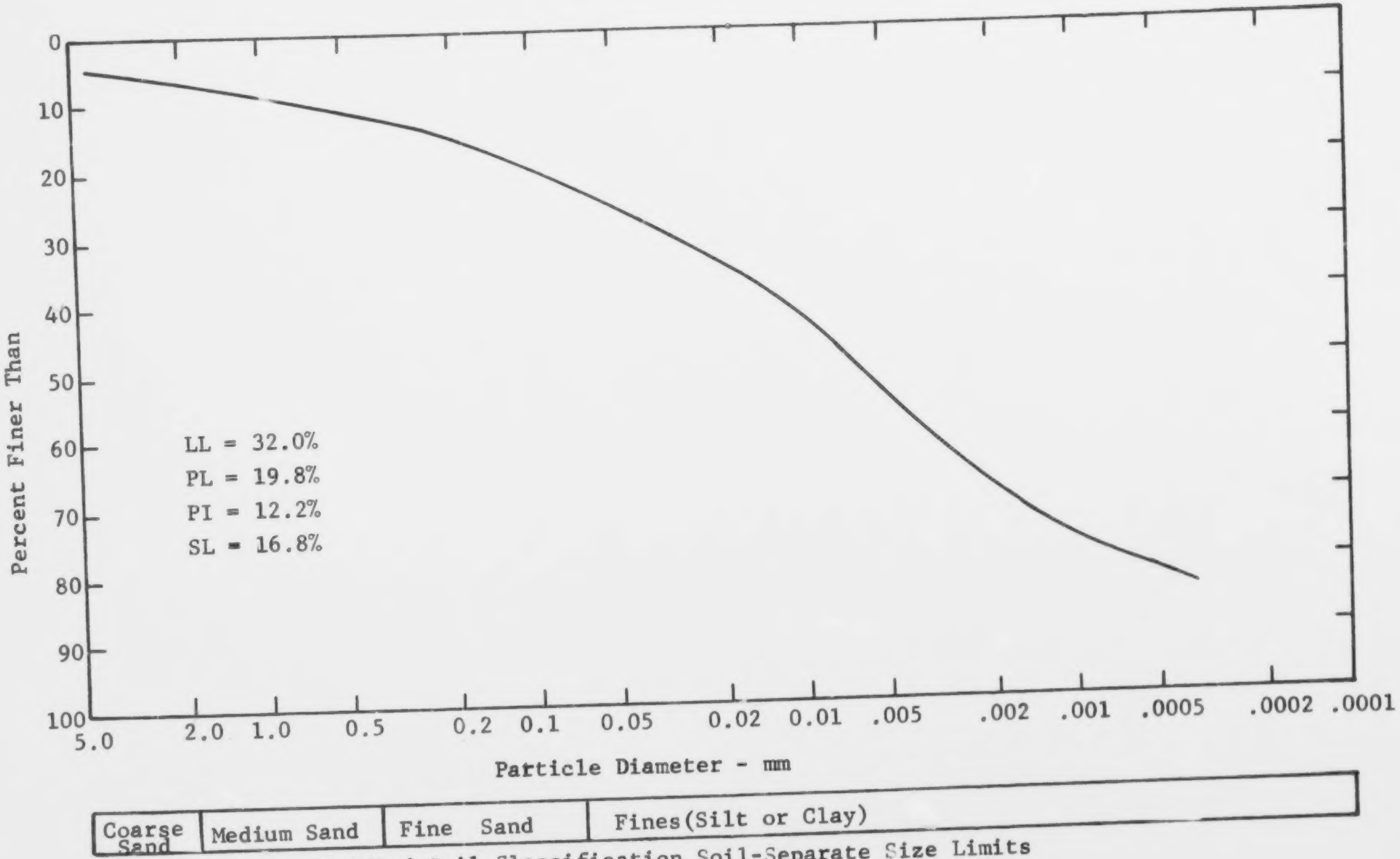


Figure 12 CBR FOR PARK FOREST CLAY



Unified Soil Classification Soil-Separate Size Limits

Figure 13 PARTICLE SIZE DISTRIBUTION FOR CHICAGO CLAY

particles have approximately the same particle size distribution as the Park Forest Clay. The Atterberg limits were also close to those for the Park Forest clay. The natural water content for this soil was 26.5 percent which is much above the plastic limit. This high water content in all probability is the reason why this material is not used in a controlled landfill. The soil used was obtained from a sewer excavation beneath Polk Street at Hermitage Ave. in Chicago at a depth between 15 and 20 ft.

The effect of the 10, 20 and 30 percent proportions of sludge on the soil properties is summarized in Table 12. The added sludge causes the plastic limit to increase while the liquid limit remains constant resulting in a lowered plasticity index. The shrinkage limit increased. The compaction characteristics for both the standard and modified tests showed a decrease in optimum dry density with the optimum moisture almost constant. The compaction curves are shown in Fig. 14-15. The sludge caused the CBR to increase at the low compaction effort and to decrease for the higher compaction effort (Fig. 16). When soaked, the CBR decreased for both compaction efforts. The sludge also increased the amount of swelling due to soaking. It was also observed that the sludge increased the workability of the soil.

The results for the Chicago clay were similar to those observed for the Park Forest clay. The soil in its natural state must be dried before it can be used in a controlled fill and mixing it with dry sludge facilitates drying and increases workability so that further drying can be accelerated. The addition of 30 percent sludge changed the properties enough so that the classification was changed from A-6 to A-4 in the AASHO and from CL to ML in the Unified Classification Systems.

3. Lake Calumet Sand

The Lake Calumet sand is classified as A-3 in the AASHO and SW in the Unified Soil Classification Systems. Typical in this classification are fine beach sands. These soils lack

Table 12

SUMMARY OF TEST RESULTS FOR CHICAGO CLAY

		Atterberg Limits				Standard Compaction					Modified Compaction					Classification		
Sludge Percentage	Specific Gravity	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Shrinkage Limit, %	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Swell, %	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Swell, %	Group Index	AASHO	Unified
0	2.697	32.0	19.8	12.2	16.8	14.0	118.5	6.5	6.6	0.48	12.1	127.2	37.2	16.5	1.53	8.6	A-6	CL
10	2.694	32.4	21.0	11.4	17.8	16.0	116.1	8.8	5.3	0.35	10.9	126.1	17.7	12.2	1.94	8.5	A-6	CL
20	2.691	33.0	22.5	10.5	19.5	15.2	113.8	11.0	7.8	0.24	12.0	123.9	26.2	8.0	2.23	7.8	A-6	CL
30	2.688	32.4	25.5	6.9	21.4	15.0	112.5	16.5	2.6	0.61	12.1	123.2	18.9	13.8	0.90	8.0	A-4	ML

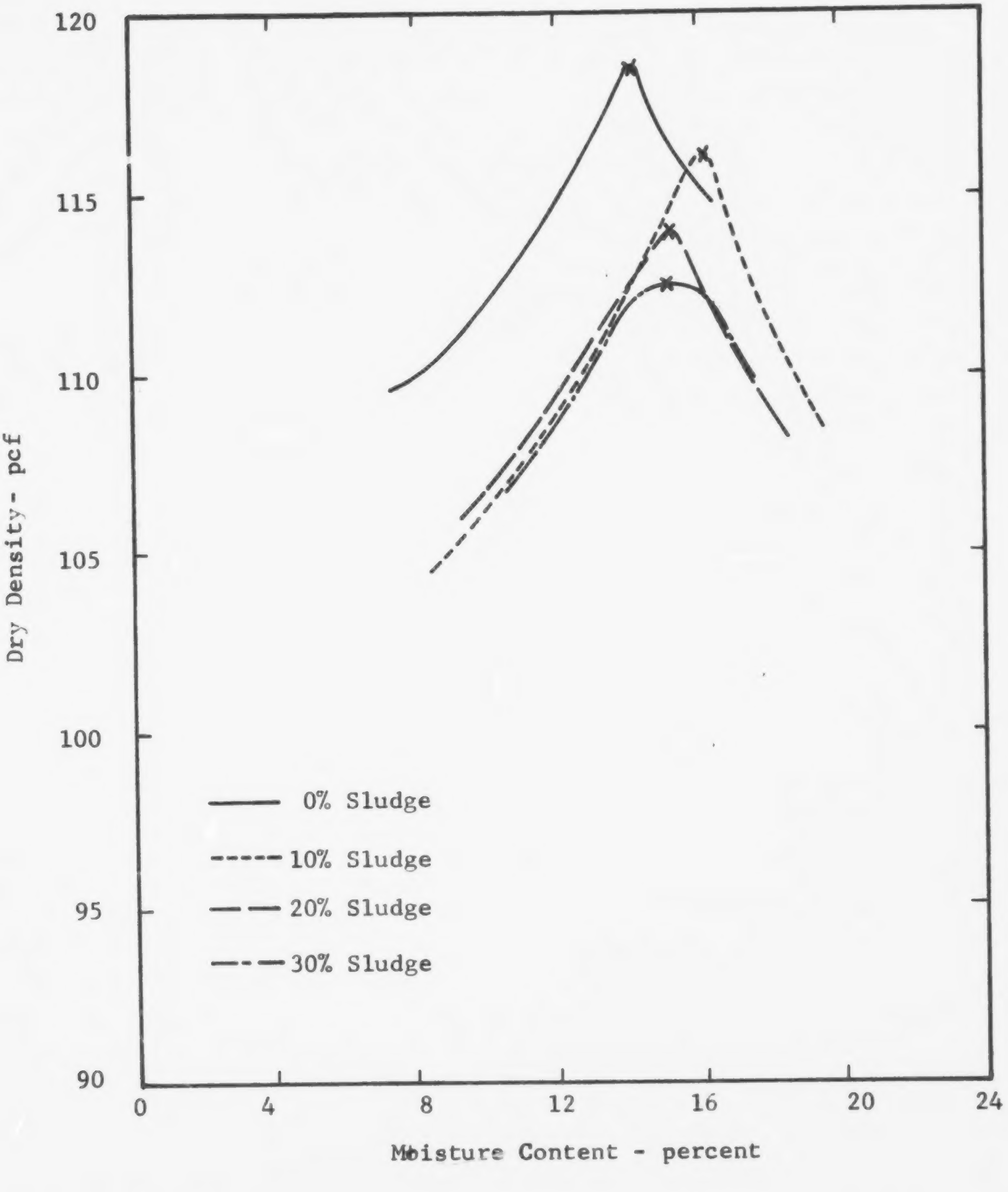


Figure 14 STANDARD COMPACTION CURVES FOR CHICAGO CLAY

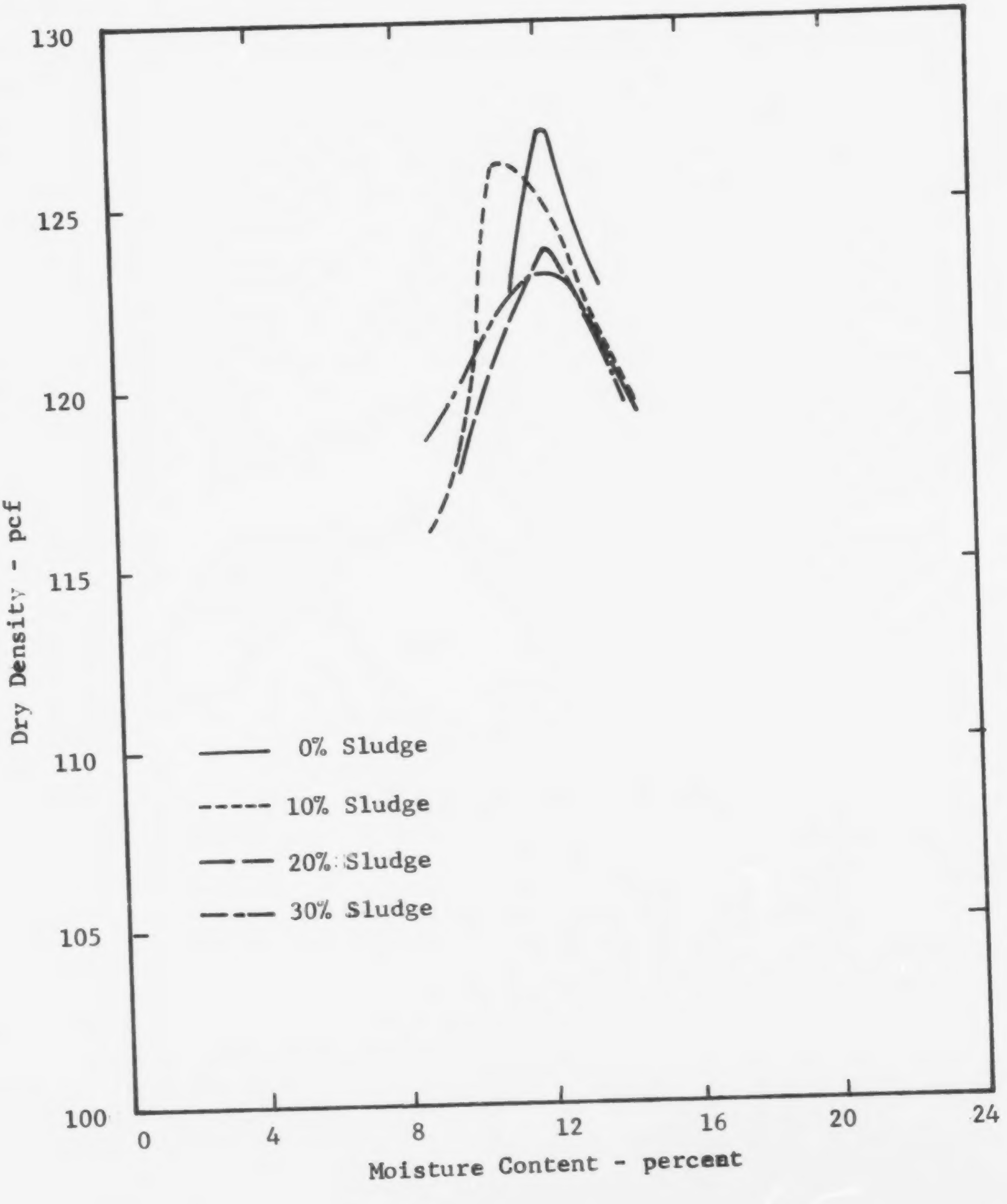


Figure 15 MODIFIED COMPACTION CURVES FOR CHICAGO CLAY

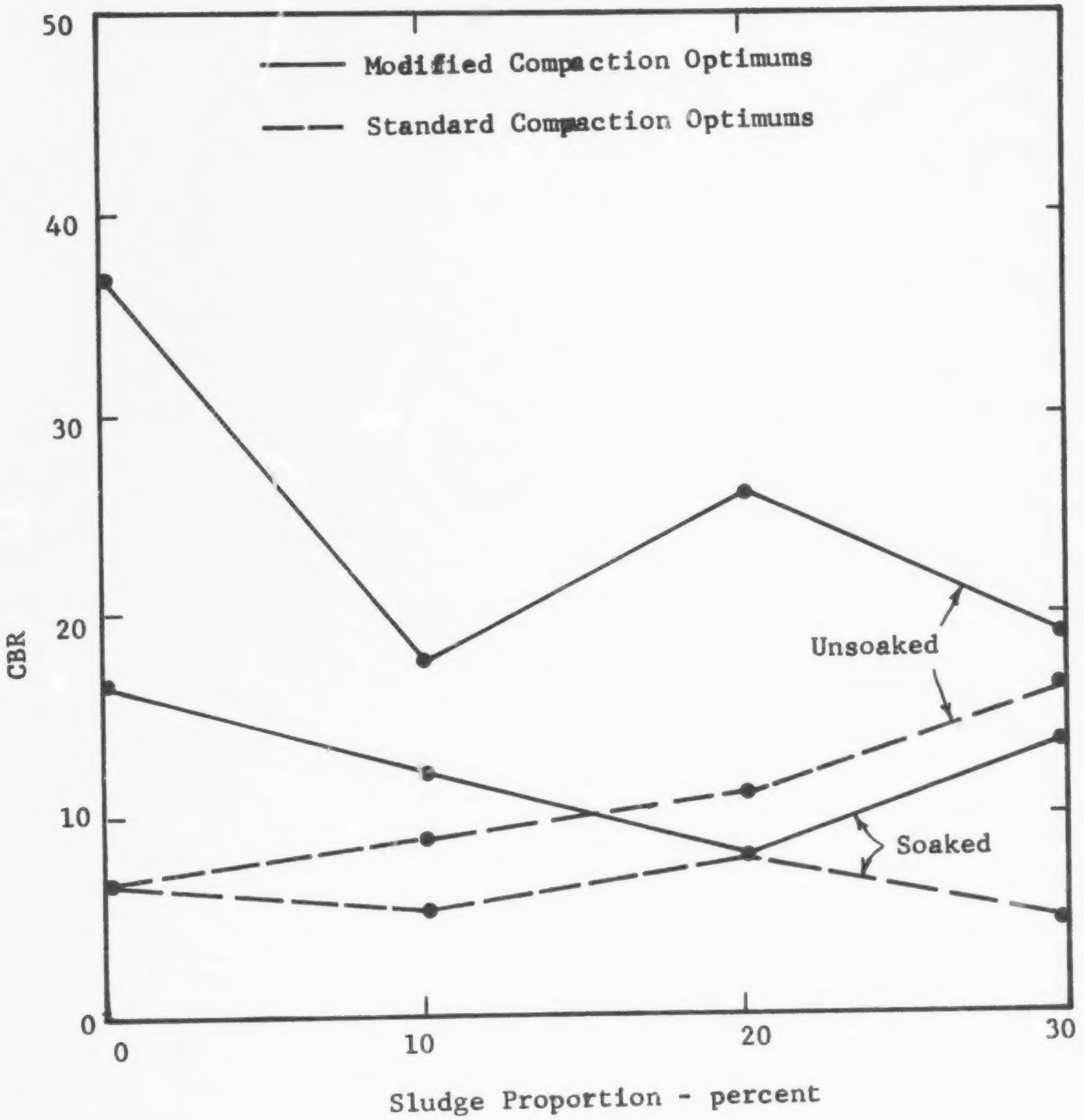
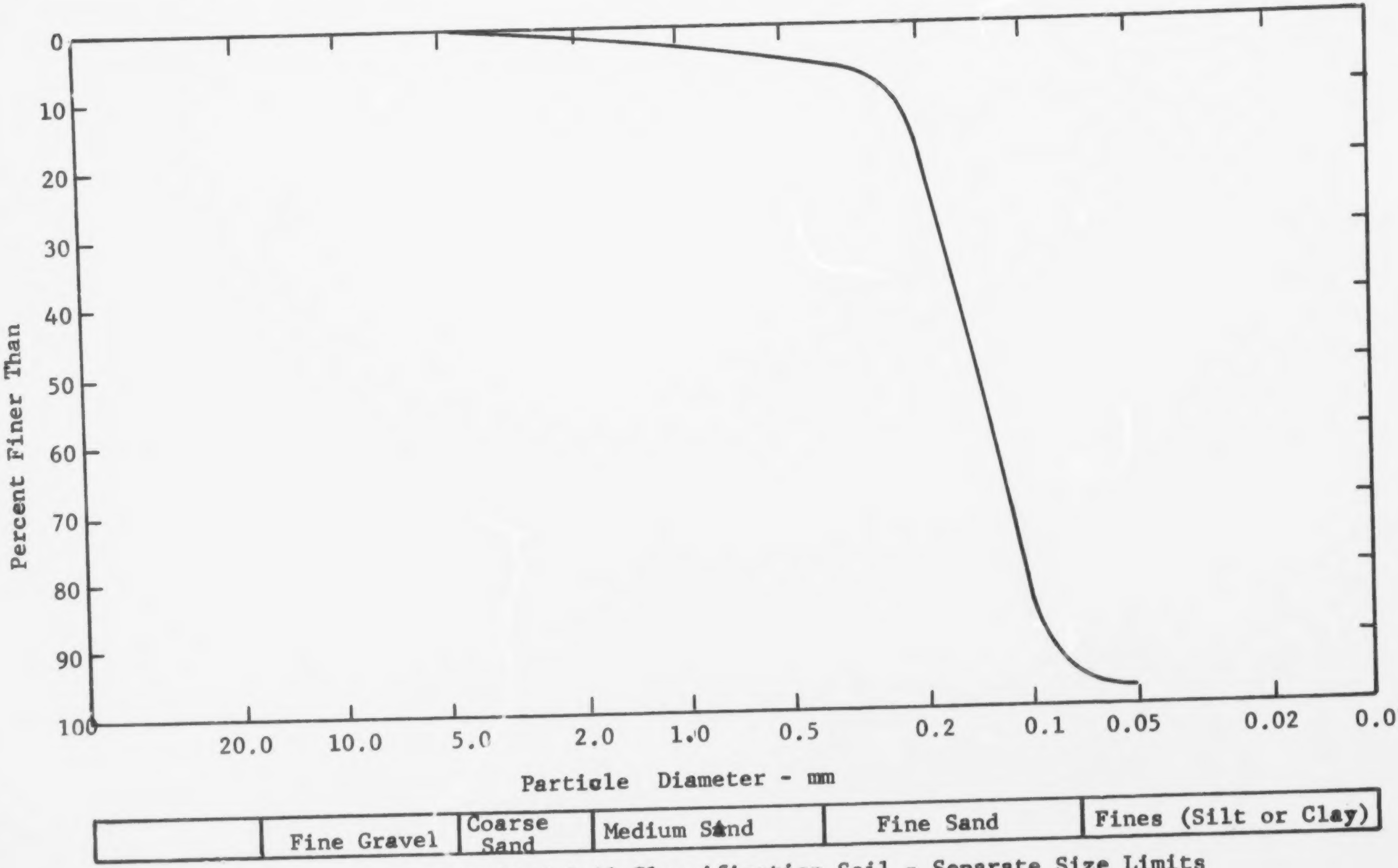


Figure 16 CBR FOR CHICAGO CLAY

stability under wheel loads except when damp and are suitable for subgrade when confined. They are affected only slightly by moisture conditions. The sand used was obtained from an excavation along the shore of Lake Calumet near the southwest tip of Lake Michigan and is a beach type sand deposited when Lake Michigan was at a higher elevation.

The graduation curve for the sand is shown in Fig. 17 and the effects of 10, 20 and 30 percent sludge proportions on its properties are given in Table 13. The sludge decreases the optimum moisture content and increases substantially the maximum dry density for both the standard and modified compaction tests. These results are shown in Fig. 18-19. When the sludge is added, particles finer than those already present are introduced and the effect is to fill the voids displacing air and some of the water thus reducing the optimum moisture content and increasing the maximum dry density. The CBR strength was little affected at the lower compactive effort, but was increased at the higher compactive effort for both the soaked and unsoaked conditions. These results are shown graphically in Fig. 20. There was no swelling observed for any of the specimens.

The sludge when added to this sand will be beneficial in that the sand can be compacted to a higher density and increased CBR. The moisture content at which maximum density can be obtained is also reduced so that less water would be required to be mixed with the sand before compaction. The addition of water to sands prior to compaction is usually required especially after the sand has been stockpiled or exposed for a period of time. As little as 10 percent added sludge was sufficient to change the classification to A-2-4 and SM in the classification system. The general properties of the new classification reflect the improvement observed in the soil behavior as observed from the tests. The improved properties are also similar to those observed in Florida[23/] where the sludge was used for road bed stabilization of sands.



Unified Soil Classification Soil - Separate Size Limits

Figure 17 PARTICLE SIZE DISTRIBUTION FOR LAKE CALUMET SAND

Table 13

SUMMARY OF TEST RESULTS FOR LAKE CALUMET SAND

		Standard Compaction				Modified Compaction				Classification		
Sludge Percentage	Specific Gravity	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Optimum Moisture Content, %	Optimum Dry Density, pcf	CBR	Soaked CBR	Group Index	AASHO	Unified
0	2.704	15.0	99.6	4.1	1.0	13.5	104.5	6.2	3.7	0	A-3	SW
10	2.700	12.5	106.5	1.1	1.1	13.0	109.2	8.6	6.3	0	A-2-4	SM
20	2.697	12.0	112.6	3.1	1.9	11.1	115.4	25.8	16.6	0	A-2-4	SM
30	2.694	11.3	120.8	2.8	1.0	9.0	124.2	34.9	8.3	0	A-2-4	SM

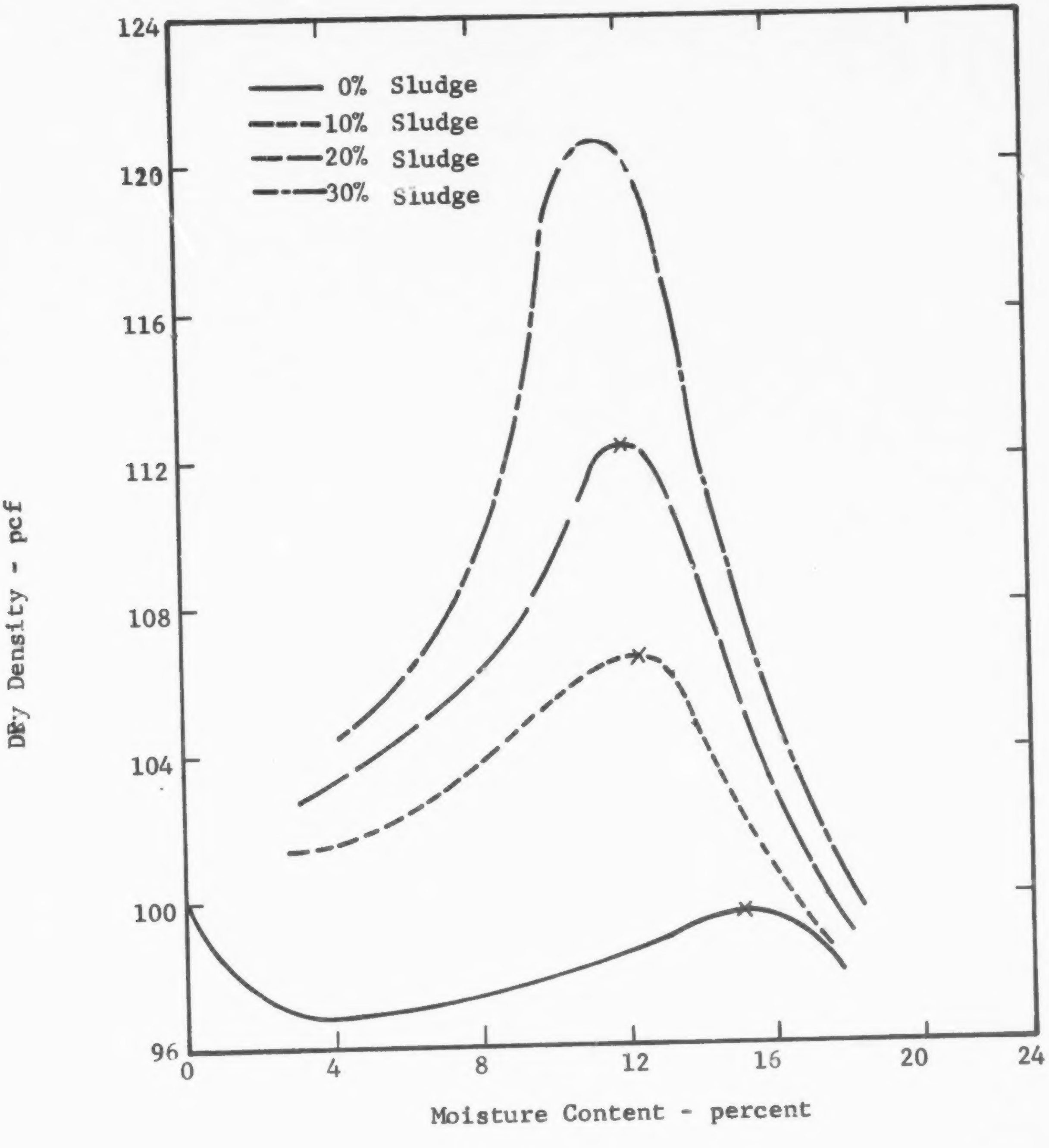


Figure 18 STANDARD COMPACTION CURVES FOR LAKE CALUMET SAND

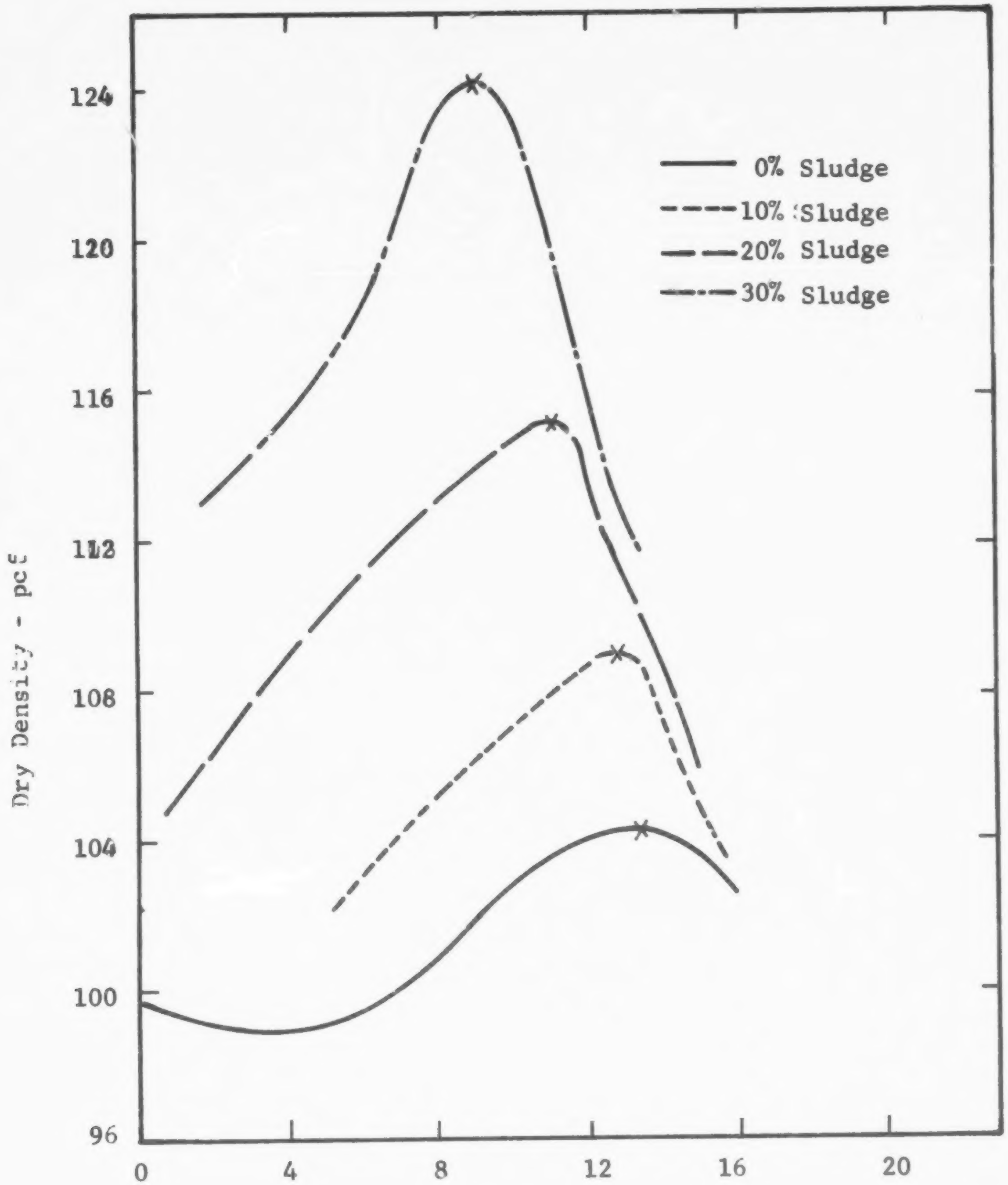


Figure 19 MODIFIED COMPACTION CURVES FOR LAKE CALUMET SAND

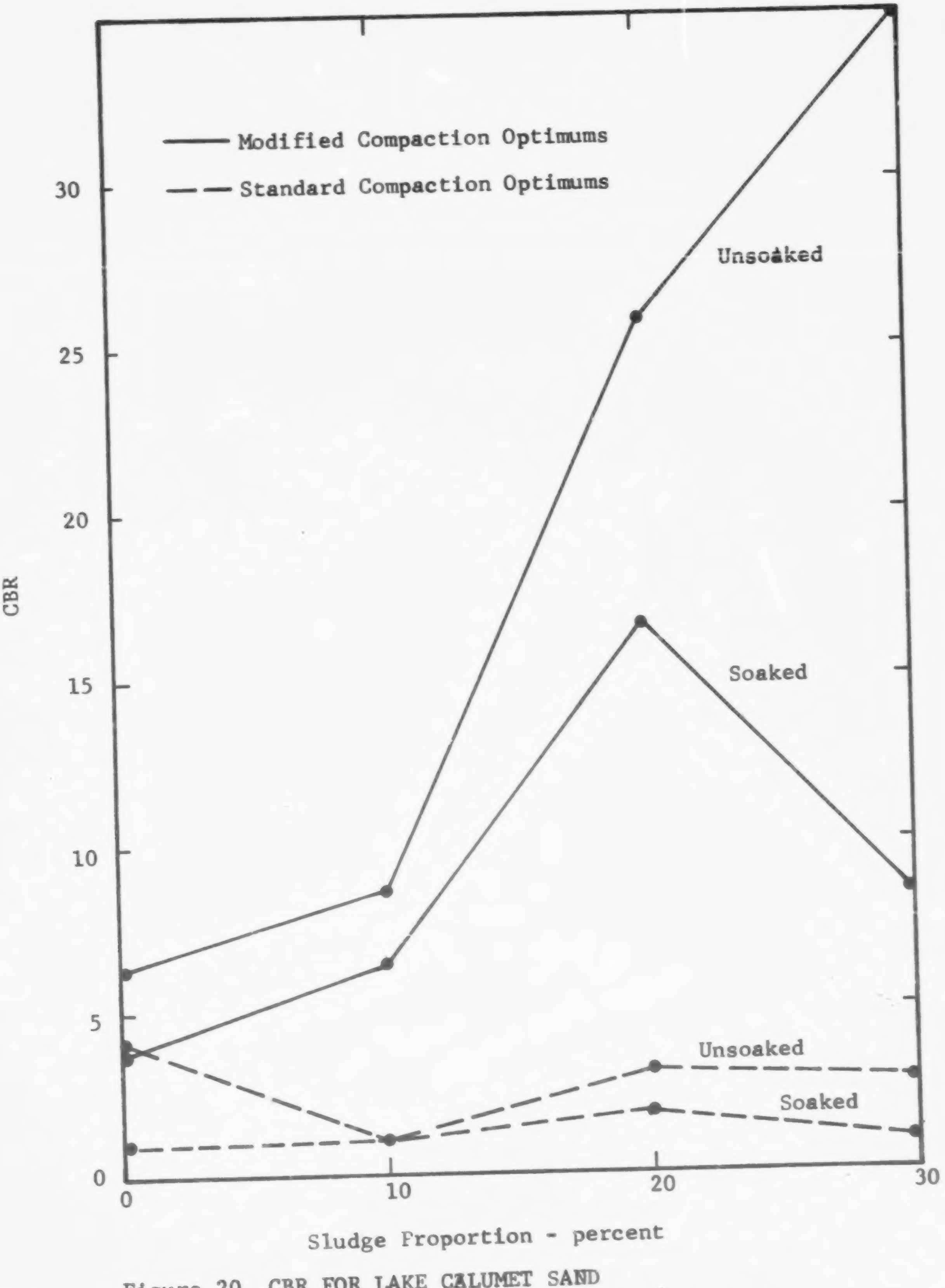


Figure 20 CBR FOR LAKE CALUMET SAND

4. Natural Organic Soil

There are areas of peat soils within the Village of Park Forest. For this reason the possibility of using the sludge to improve the soils in these areas was also investigated. The soil used for these tests was classified as OH - an organic clay of high plasticity - in the Unified Classification System. The soil was obtained from a bog area to the north of the present sludge lagoons.

The results of the tests with 25, 50 and 100 percent proportions of sludge are given in Table 14. The added sludge reduces both the liquid and plastic limits resulting in a lower plasticity index. The shrinkage limit is increased resulting in a lesser volume change when dried. The added sludge reduced the optimum moisture content and increased the maximum dry density. This is shown in the results of the Harvard miniature compaction tests given in Fig. 21.

The strength characteristics were determined from the unconfined compressive strengths which showed a reduction in strength when sludge was added with the largest reduction occurring at 25 and 100 percent sludge. However, the strain at failure increased progressively with the increase in sludge content. The tests were performed on specimens compacted to optimum moisture and dry density conditions.

Compression tests were also conducted to determine what effects the sludge would have on the total amount of settlement due to compression beneath a loaded area. The large amount of settlement that occurs when water is squeezed out of these organic soils represents a serious problem. The results of compression tests on specimens initially 1 in. thick is given in Fig. 22. The curves shown are a plot of deformation versus the log of the applied pressure. Each of the specimens was compacted to maximum dry density at its optimum moisture content as determined by the compaction tests. As shown, the specimen with 50 percent sludge had less total deformation than the specimen without sludge. There was also less rebound when the loads were removed for the sludge treated soil than for the nontreated soil.

Table 14

SUMMARY OF TEST RESULTS FOR ORGANIC SOIL

		Atterberg Limits				Harvard Compaction				Classification
Sludge Percentage	Specific Gravity	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Shrinkage Limit, %	Optimum Moisture Content, %	Optimum Dry Density, pcf	Unconfined Compressive Strength, psi	Strain at Failure, %	Unified
0	2.105	140.0	81.0	59.0	15.5	66.0	54.0	25.6	4.0	OH-Pt
25	2.176	107.8	76.5	31.3	22.4	64.3	56.3	14.2	4.2	OH
50	2.290	92.5	71.5	21.0	34.5	58.0	58.2	23.9	5.6	OH
100						55.5	59.7	10.4	8.7	

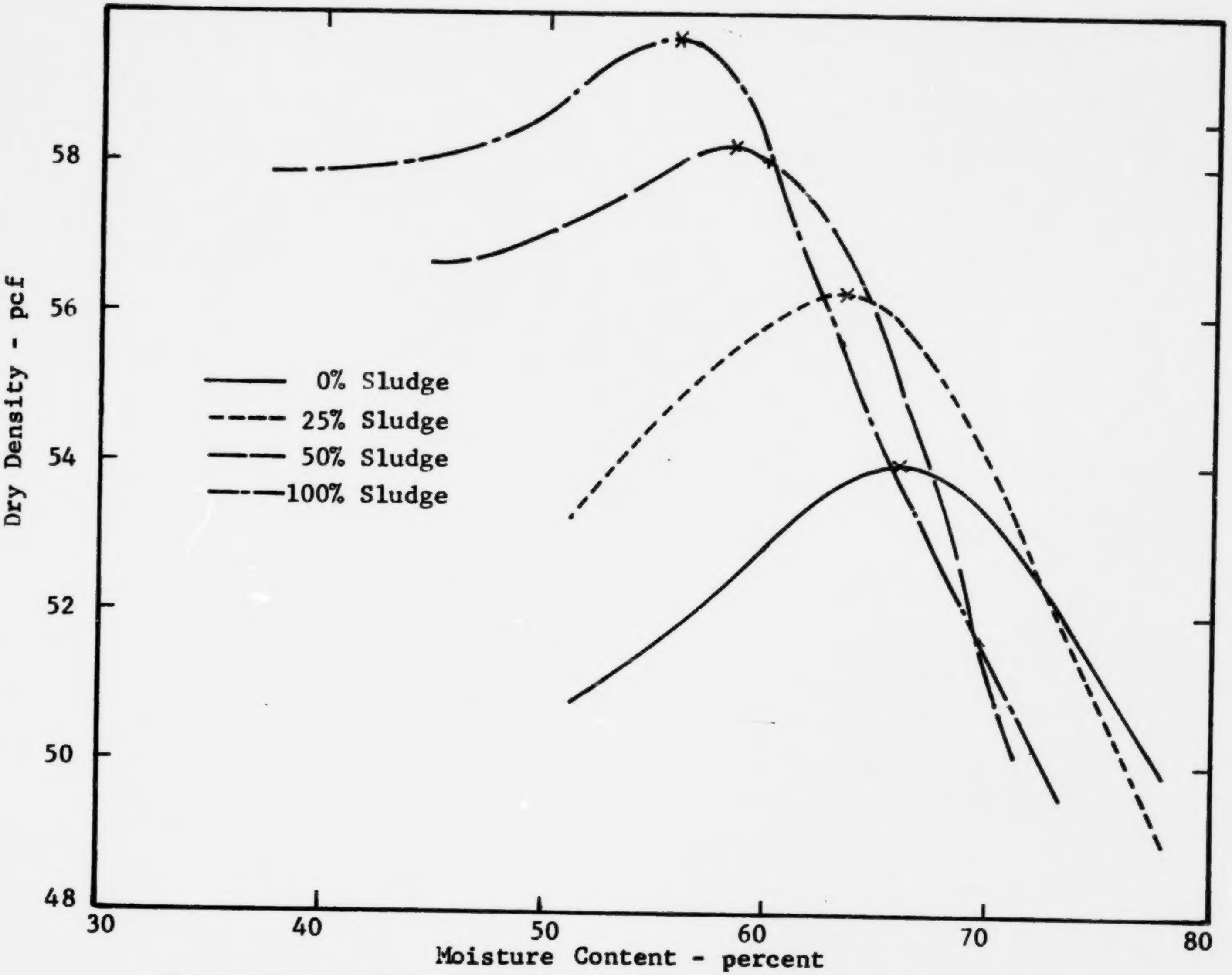


Figure 21 COMPACTION CURVES FOR NATURAL ORGANIC SOIL

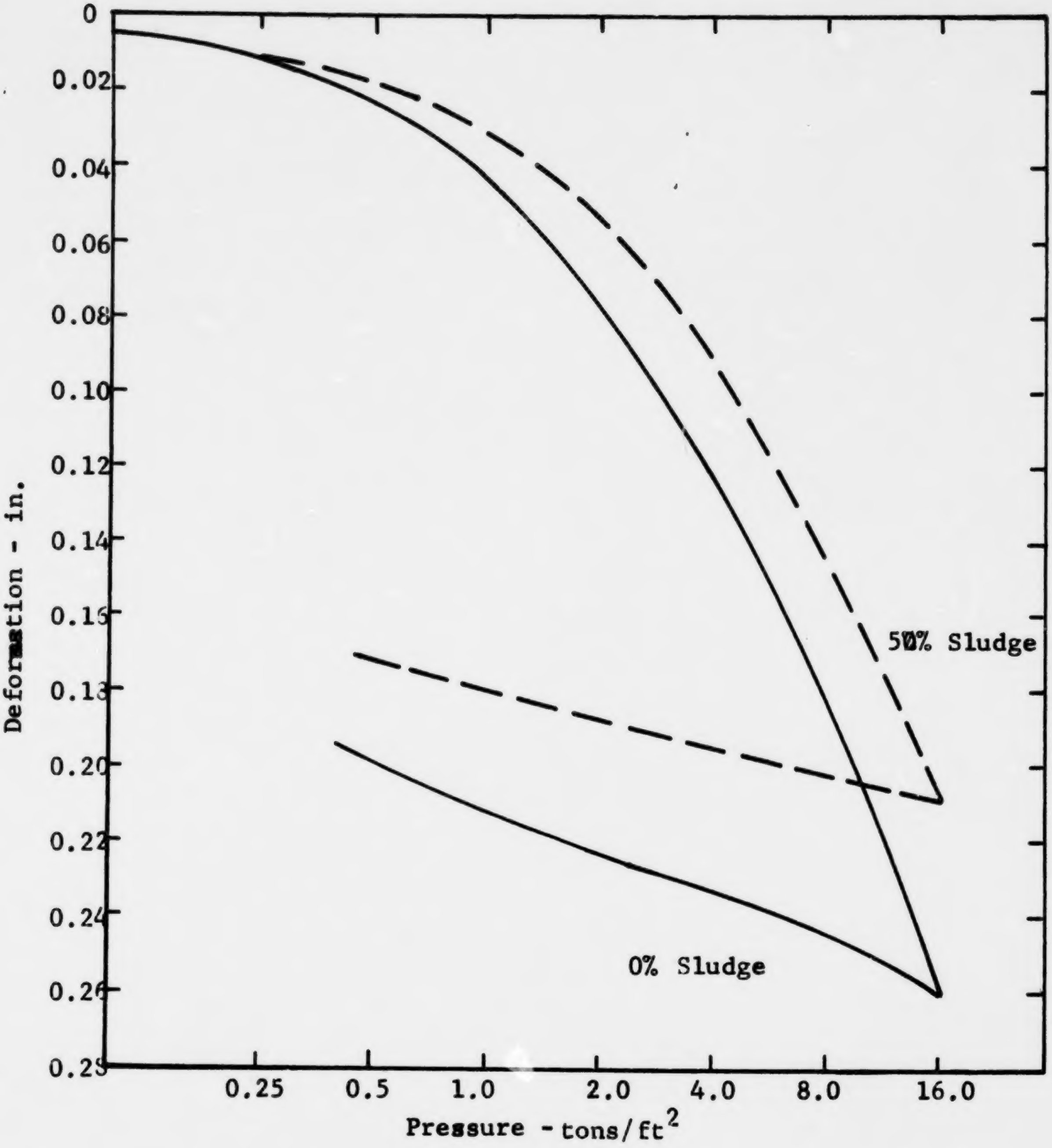


Figure 22 LOAD DEFORMATION FOR NATURAL ORGANIC SOIL

It was also observed in preparation of specimens that the sludge increased the workability of the soil.

The results have shown that the sludge can be used to improve the properties of an organic soil. Although the soil may not be improved to the point where it can support large loads without excessive settlement it may improve some areas in conjunction with proper drainage facilities so that they can be used to support small buildings.

The results of the aforementioned investigations have shown that the sludge may be mixed with existing soils and has no detrimental effects. In the clay soils the added sludge increased the workability and reduced the amount of drying shrinkage. The greatest effect was achieved on sand where the sand filled the voids and increased the soil density and bearing strength.

In all of the tests reported the sludge as a dry powder was thoroughly mixed with the soils. To achieve similar results in field operations the sludge should also be mixed with the soils by spreading and discing or mixing with a pulverizing type mixer. In most cases the soils from borrow areas are at a moisture content above the optimum at which they are to be compacted. Therefore, the sludge to be added should be almost dry.

D. LANDFILL

An evaluation of the sludge material as a soil by itself was made to determine its suitability for landfill.

The sludge as a soil is nonplastic and would be classified as an A-4 in the AASHO and ML in the Unified Soil Classification Systems. Included in these soils are inorganic silts, very fine sands, rock flour and silty or clayey fine sands. The grain structures of these soils is such that they are subject to frost heave. The pores are small enough so that high capillary forces can develop yet are large enough that a sufficient flow of water can occur so that ice lenses can form and grow.

The compaction curves for this material are given in Fig. 23. These tests show a substantial reduction in optimum moisture and increased optimum dry density in the modified test as compared to the standard test. The higher compactive effort causes the particles to pack closer together thereby displacing water.

The sludge itself may be used as a fill under carefully controlled conditions. But because of the sharp peaks of the compaction curves, there is a narrow range of moisture content at which it can be satisfactorily compacted. Also, the sludge should be placed where its moisture content is not subject to wide fluctuations. The sludge should be isolated from a constant source of water or else protected from freezing to prevent excessive heave. The lack of plasticity would make the soil highly erodible by surface water and powdery when dry making it subject to wind erosion if left unprotected.

Although it is possible under special conditions to use the sludge as a fill material by itself a much better material can be obtained if it is first mixed into a clay to provide plasticity or with a sand to increase the average particle size. As illustrated previously, the sludge would increase the strength of the sand and increase the workability of the clay while not changing its other properties appreciably.

The material may also be used to advantage in sanitary landfills,based on its effects on natural organic and agricultural soils.

E. AGRICULTURAL SOIL CONDITIONER

The direct liming of soils consumes a large amount of limestone products.[16/] Between 1957 and 1963 the annual consumption in the U. S. was 22.5 million tons with Illinois the leading state with 3.25 million tons. The peak consumption occurred during 1947 with the decline since then attributable to less vigorous promotion by USDA in connection with its soil conservation program and reduction in funds for purchasing liming materials. The declining equivalent income of the farmer also has contributed to the reduction in its use. Of the materials now used for this purpose about 75 percent is subsidized.

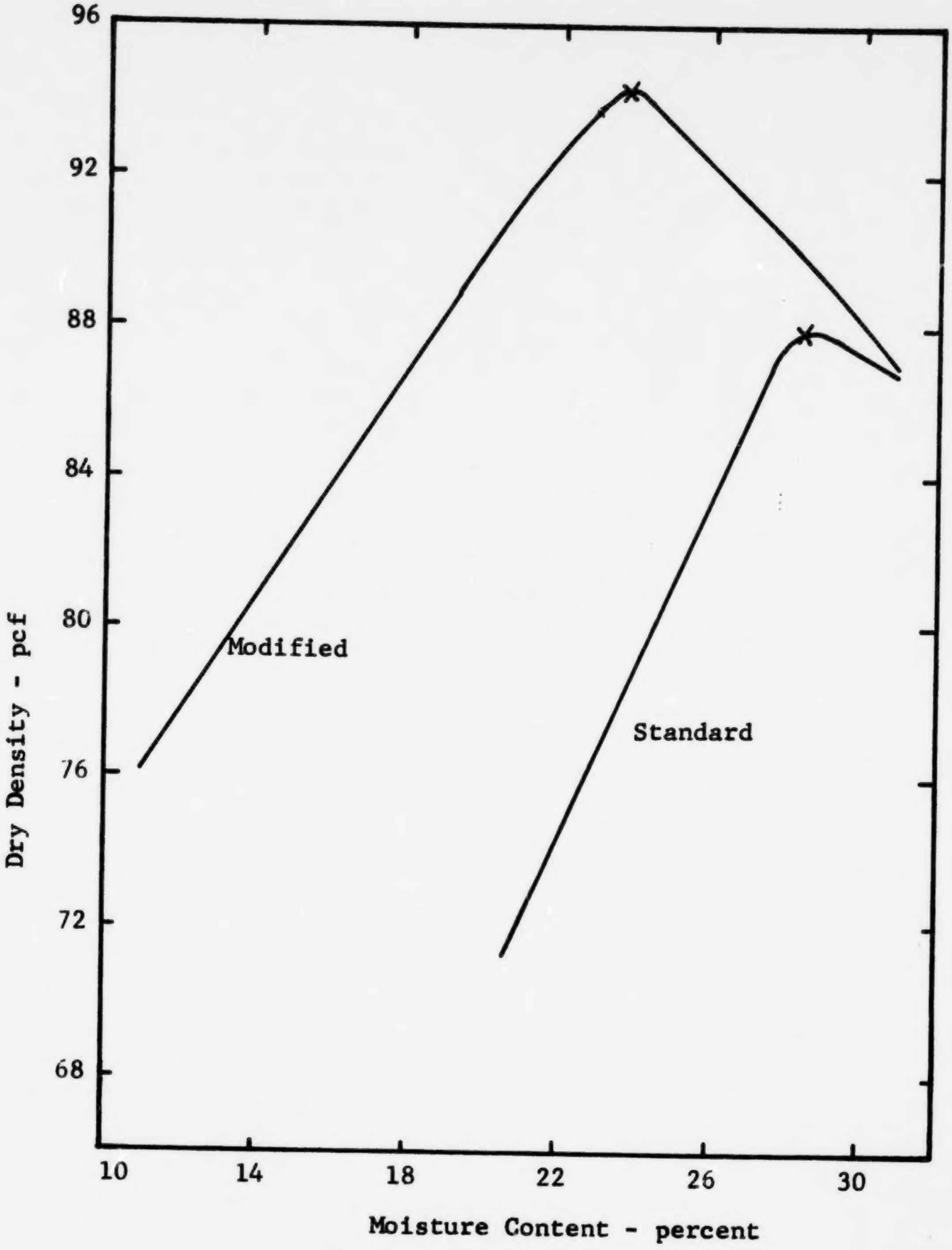


Figure 23 COMPACTION CURVES FOR SLUDGE SOLIDS

Limestone provides 97.5 percent of all agricultural liming materials. The remaining 2.5 percent includes the more concentrated and expensive materials like lime and the less concentrated materials and calcareous wastes such as water softening sludge.

Liming is practiced in the part of the U. S. east of the 100th meridian. The ten top states for 1962 were all located in the northern half of this area. The soils to the west of the 100th meridian are arid and largely alkaline except for a few acid, moist soil areas in the west coast states.

The advantages of liming are described as follows and are in the order of relative importance.

1. Neutralize Soil Acidity: Most crops grow well in neutral to slightly acid conditions in a soil pH range of 6.5 to 7.
2. Direct Source of Plant Nutrients: Liming supplies the essential nutrients, calcium and magnesium, directly to support plant life.
3. Increases Supply of Other Nutrients: Other available plant nutrients are liberated from the soil organic matter.
4. Increases Organic Matter: Liming increases organic matter by promoting larger and more profilic plant growth and accelerates the decomposition of vegetation into humus.
5. Increase Soil Micro-organisms: The earthworm population usually increases as the pH is raised up to neutral.
6. Improve Soil Tilth: Liming materials make the soil more workable and friable and facilitate cultivation. The fine clays which would dry into hard clay lumps are broken up more easily.
7. Provides Source of Trace Elements: Limestone contains many trace elements the most important of which are manganese, copper, zinc, boron and molybdenum.
8. Increases Efficiency of Fertilizers: Liming increases the availability of certain fertilizer elements.

The application of the liming materials are usually done by independent lime spreading companies or local truckers who purchase and haul the limestone from the producer and provide the spreading service. The material is spread by self-unloading dump or tank type trucks with a spreader attached.

The most effective way to apply the liming material is to plow under the soil about one-half the liming increment and harrowing in the remaining half. In this way the subsoil and upper-top soil receive an even distribution of material. Application only to surface benefits top 2 to 3 in. during the first year and generally requires several years to raise pH 4 to 8 in. below surface. Another, method is to apply the liming material on a liguminous cover crop just before plowing it under. The liming material accelerates decomposition of the roots and foilage and counteracts the nitric acid released in the decomposition.

Liming applications are made every 4 to 6 years with smaller and more frequent applications being more desirable on sandy soils. Areas of high rainfall causing calcium and magnesium loss through leaching and erosion and intensity of cropping may necessitate more frequent liming. The most effective barameter for application is the soil pH. Over liming should be avoided because raising an acid soil to a pH greater than 7 does not make plants more productive or may even reduce productivity from the 6 to 7 pH range although many plants will thrive in the 7 to 8 pH range.

The neutralizing efficiency of a liming material is measured by its total neutralizing power (TNP). Table 15 shows the relative values of pure liming materials. The relative neutralizing values are based on 100 for pure calcium carbonate. All of the other materials have relative values greater than that for calcium carbonate because the molecular weights of all the compounds are less than that for calcium carbonate. Fineness and particle gradation is also a consideration in evaluating liming materials. Agronomists generally agree that neutralizing efficiency

Table 15

RELATIVE NEUTRALIZING VALUES FOR PURE LIMING MATERIALS

Material	Relative Neutralizing Value	Pounds of Liming Material Equivalent to 1 Ton	
		Calcium Carbonate	Calcium Oxide
Calcium carbonate	100	2000	3570
Magnesium carbonate	119	1680	3000
Calcium oxide	178	1120	2000
Magnesium oxide	250	800	1430
Calcium hydroxide	135	1480	2640
Magnesium hydroxide	172	1160	2070
Dolomite	108	1850	3330
Dolomite hydrate	175	1145	2040

Table 16

APPROXIMATE RATE OF LIMING TO RAISE SOIL pH 1.0

Soil Type	CaO Equivalent Per Acre (lb)		
	Low Organic Content	Medium Organic Content	High Organic Content
Clay or silt loams	1500	1750	2000
Loams	1000	1250	1500
Sands or sandy loams	500	750	1000

rises as fineness of the various limestones used increases. Stone particles of No. 100 mesh dissolve and react with soil acids in 2 to 4 weeks whereas No. 10 mesh requires 6 to 12 months or longer. The trend has been to the larger size materials because price increases as fineness increases and farmers will be more amenable to purchase their full requirements at the lowest price. However, these materials are so slow to react that the long-range results are not visible causing the farmer to be apathetic about liming.

The approximate amount of liming materials required to raise the pH 1.0 is given in Table 16. The amounts shown are expressed as calcium oxide equivalent per acre which are given in Table 15 for various pure compounds.

Water softening sludge is suitable to be used as a liming material. The sludge produced by the Village of Park Forest containing both calcium carbonate and magnesium hydroxide would provide both calcium and magnesium. The sludge from Park Forest containing 84 percent calcium carbonate and 11 percent magnesium hydroxide would have a relative total neutralizing value of 103. This is the same value of a dolomite limestone with 95.5 percent carbonate content. The fineness of the sludge should provide a very fast reaction time and produce almost immediate results if it is mixed into the soil. A clay or silt loam of low organic content requiring 1500 lb of CaO per acre to raise pH 1.0 will require an application of 2.2 tons sludge per acre. At this rate of application the sludge from a 3 mgd output would supply liming materials to treat 5 acres of farm land.

It may also be advantageous to mix the sludge into soils used in embankments and fills to promote vegetation growth to prevent both wind and water erosion.

The property of the sludge materials to accelerate the decomposition of organic materials can be used in natural organic soil and sanitary landfills to break down the organic materials to more stable ones. It may also be possible to mix the sludge with sewage sludge to increase the fertilizer value.

The probable reason why more of this sludge material is not used for this purpose is the difficulty in handling and application of the wet sludge. The sludge, if dewatered so that it is easily handled and spread, can readily be utilized for liming of agricultural soils where needed. A totally dry material would not be required as it would cause a dust problem during spreading. However, the sludge if given away by the water plant would be competing with a material that can be purchased for $1.70/ton (1962) which does not provide much of an economic incentive unless the sludge is such that it can be easily handled and applied. Long hauling distances would also reduce or eliminate any economic incentive.

Limestone is also used for other agricultural purposes such as fillers in fertilizers and as an ingredient in mineral feed supplements. Water softening sludges are not suitable for these uses because it is too fine for fertilizer where a coarser material with the same grain size as the other plant nutrients is required and it does not have the calcium carbonate purity required for mineral feed supplements.

In recent years direct liming has been started on forest sapplings and orchard trees in the U. S. and has been done much more extensively in Germany. Direct liming may also benefit in another way in that strontium 90 in radioactive fallout is absorbed less by plants from well limed soils than soils lacking calcium. This is particularly dreaded because the stontium 90 is assimulated by livestock through fodder and pastures and by humans through food intake.

Information on the potential use of the sludge from Park Forest for use as an agricultural soil additive was obtained from the University of Illinois Cooperative Extension Service. They stated that the sludge may be used for this purpose but that most soils in the area are presently at the right pH level and the addition of the sludge would make it too high. The addition of magnesium to the soil would also increase the magnesium toxicity.

VI. SUMMARY

There are many possible methods in which water softening sludge may be utilized. Almost all of these would require the sludge to be in dry powder or almost dry condition. This condition for use, lack of dewatering, and the difficulty in handling at high moisture contents is the primary reason why the material is not presently used for these purposes.

The characteristics of lime water softening sludge is dependent upon the softening process and the materials removed from the water. The sludge from the Village of Park Forest Water Treatment facilities contains about 84 percent by weight calcium carbonate, 11 percent magnesium hydroxide, and 5 percent miscellaneous which include fine sand and compounds of aluminum and iron. The middle 90 percent of the particles range in size from 1.5 to 30 microns.

This material is suitable for use as a mineral filler in such products as paints, floor coverings, caulking compounds, and bituminous products.

The sludge can also be mixed with soils from the Park Forest area to improve their properties. In clays the added sludge increases the workability and friability making them easier to handle and manipulate. In organic soils the added sludge decreases the organic content per unit volume and reduces the amount of settlement due to surface loads. When mixed with sands the sludge fills the voids and results in a denser and stronger material when compacted. The best results are obtained if the sludge is well mixed into the soils. The sludge can also be used in land fill under controlled moisture conditions. If used by itself it would be subject to frost heaving and loss of strength with changes in moisture content. Therefore, it could be better used for landfill if it was mixed into a clay to provide plasticity or with a sand to increase the average particle size.

The sludge can be used as a filler in concrete where a filler is required to prevent bleeding, improve pumping properties, and decrease permeability without adversely reducing the strength and increasing drying shrinkage.

It can be used as an agricultural liming material to increase soil pH and improve soil fertility. The application need not be restricted to farm land and may be used to neutralize any soil to promote growth. Such applications might be parkways, roadway embankments, and drainage ditches or waterways where growth would prevent erosion.

The best method of dewatering the sludge is the vacuum filter. It is not only the most economical of those considered (vacuum filtration, centrifuging, lagooning, and sand bed drying) to be employed at Park Forest, but the air passages induced in the filter cake during the filtering operation accelerates air drying. This further improves the handling characteristics of the sludge and enhances the utilization possibility. The vacuum filter also yields an economic benefit derived from the recovery of the water and returning it to the plant.

The dewatering installation for the Village of Park Forest would require the installation of the following facilities.

Sludge thickener: A 32 ft dia sludge thickener is required to prethicken the sludge prior to filtration to increase efficiency of the filter and to permit intermittant operation.

Vacuum Filter: A 8 ft dia by 10 ft long vacuum filter is required. This machine would require about 6 hours of operation per day to handle the solids generated by a 3 mgd output.

Building: A 20 ft by 32 ft heated building is required to house the filter on an elevated stand so that the sludge cake can be deposited directly into a truck parked below.

Lagoon: A 90 ft by 70 ft x 6 ft lagoon is required for emergency situations. This lagoon can provide a storage for 4 days output at 3 mgd of dilute sludge or 12 days output of sludge thickened to 10 percent solids.

Truck: A truck is required to haul dewatered sludge to a disposal site or stockpile for future use.

The estimated annual cost for this installation is $21,740 which includes a $13,800 allowance for the water recovered.

The unit costs for this installation are $6.02/ton dry solids and $19.95/million gallons of water softened.

This cost includes the necessary piping, valves, and pumps to complete the installation and annual depreciation, interest, operating, maintenance, and manpower costs. There are no land costs included because it was assumed that land at the plant site is available for the installation of facilities and that land could be made available at no charge for disposal or stockpiling of the dewatered sludge.

The installation of a centrifuge, a lagoon at a site 3.5 miles from the plant and sand drying beds required annual costs of $25,825, $34,865 and $35,475 respectively. The installation of recalcining facilities to reclaim lime was not considered because of the relatively small output of the plant, the magnesium content of the sludge, and proximity to large commercial lime producers.

VII. RECOMMENDATIONS FOR FOLLOW-ON WORK

This report has indicated that water softening sludge can be dewatered on a vacuum filter and that the sludge has a potential use as a mineral filler in paints, floor coverings, and bituminous paving concrete and as a soil admixture and/or soil conditioner. It is therefore recommended that the following work be done as a follow-on to this study.

1. Conduct an analysis of the recommended vacuum filter dewatering system, if this system is installed at the Park Forest plant, to correlate the full scale operation with the laboratory tests and to optimize its operating parameters to provide the most efficient operation.
2. Work with the paint and floor covering manufacturers in the Park Forest area on the use of the sludge in their products and to determine what further processing would be required. A sample of the sludge would then be processed for use on a trial basis in their products.
3. Work with asphalt plants in the Park Forest area on the use of the sludge in bituminous concrete and determine what further processing would be required. A sample of the sludge would then be processed for use in trial batches.
4. Mix the sludge into natural organic soils, clays, and sands in the Park Forest area. Observe the performance of these test plots in relation to similar plots not treated with sludge.
5. Use the sludge in test sections of a sanitary landfill and observe their performance in relation to other sections not containing sludge.

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APPENDIX I

VACUUM FILTER SIMULATION TESTS

The vacuum filter simulation tests were conducted using an apparatus shown schematically in Fig. 24 and 25. The tests were conducted using a filter test leaf kit supplied by the Eimco Corporation and using procedures recommended by them.[25,26] The tests were designed to provide the following data for a given filter material, sludge concentration and cycle time:

1. Filter cake weight, thickness, and moisture content.
2. Filtrate volume and clarity.
3. Vacuum level during form cycle and dewater cycle.
4. Volume of air drawn through filter cake during dewater cycle.

The test leaf was 4-1/2 in. dia and provided a filter area of 0.11 sq ft. The edges of the filter cloth were protected with a rubber sleeve so that air could pass through the filter media only on the filter face and not on the sides of the test leaf or through the edges of the filter cloth. The vacuum level was measured with a manometer connected to the test leaf so that the vacuum level recorded was that at the underside of the filter and could not be affected by other parts of the system. A large vacuum reservoir was included in the system to help maintain a constant vacuum level during the test.

The bottom loading vacuum filter was simulated by immersing the filter test leaf with the media downward into the sludge for the prescribed time period of the form cycle and then withdrawing it for the prescribed dewater cycle time. To simulate the top loading vacuum the test leaf was placed in the bottom of a container into which the sludge was placed and maintained at a given level during the form cycle. After the form cycle the excess sludge was

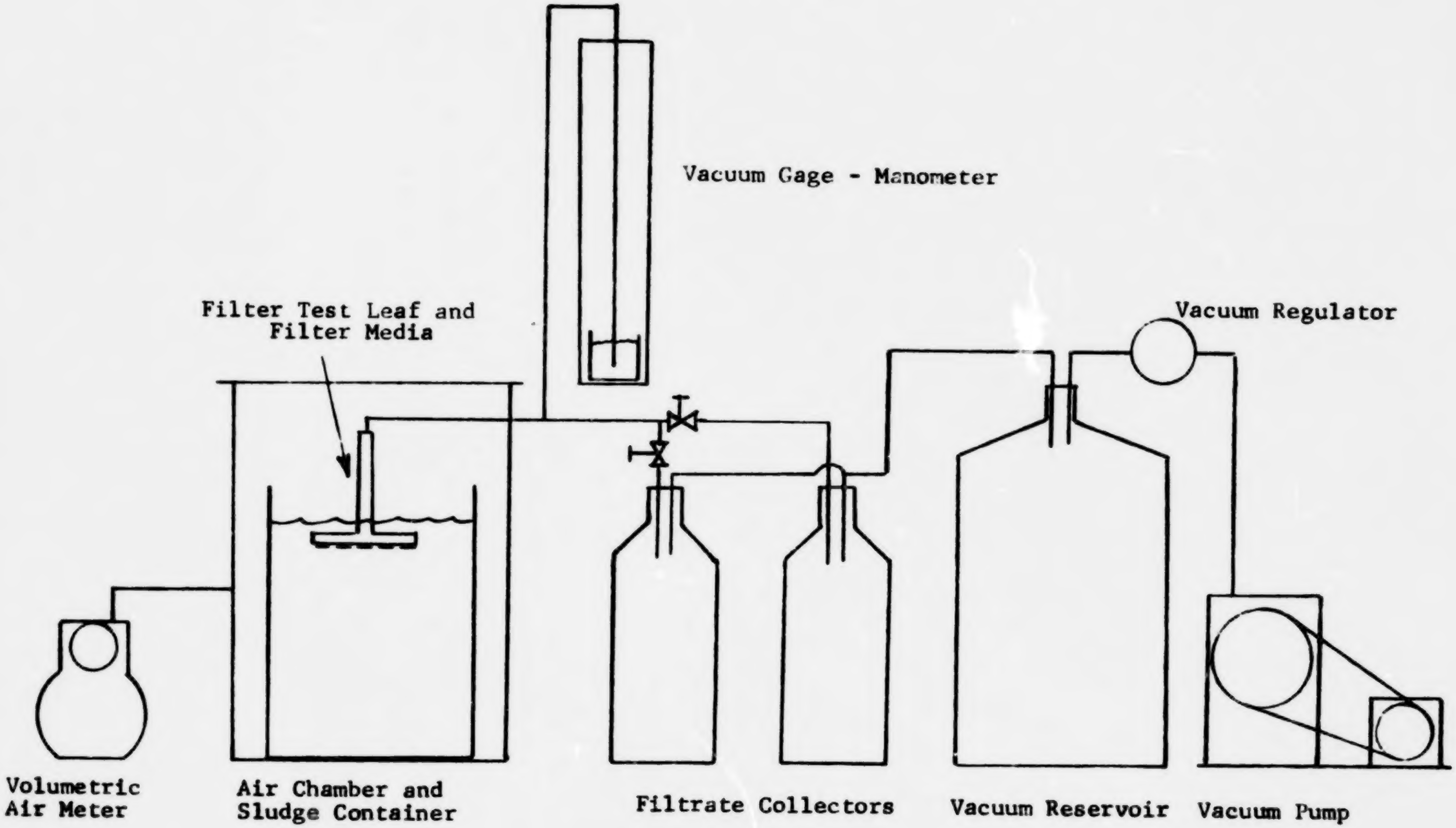
Vacuum Gage - Manometer
Filter Test Leaf and Filter Media
Vacuum Regulator
Volumetric Air Meter
Air Chamber and Sludge Container
Filtrate Collectors
Vacuum Reservoir
Vacuum Pump

Fig. 24 VACUUM FILTER SIMULATOR FOR BOTTOM LOADING TYPE FILTER

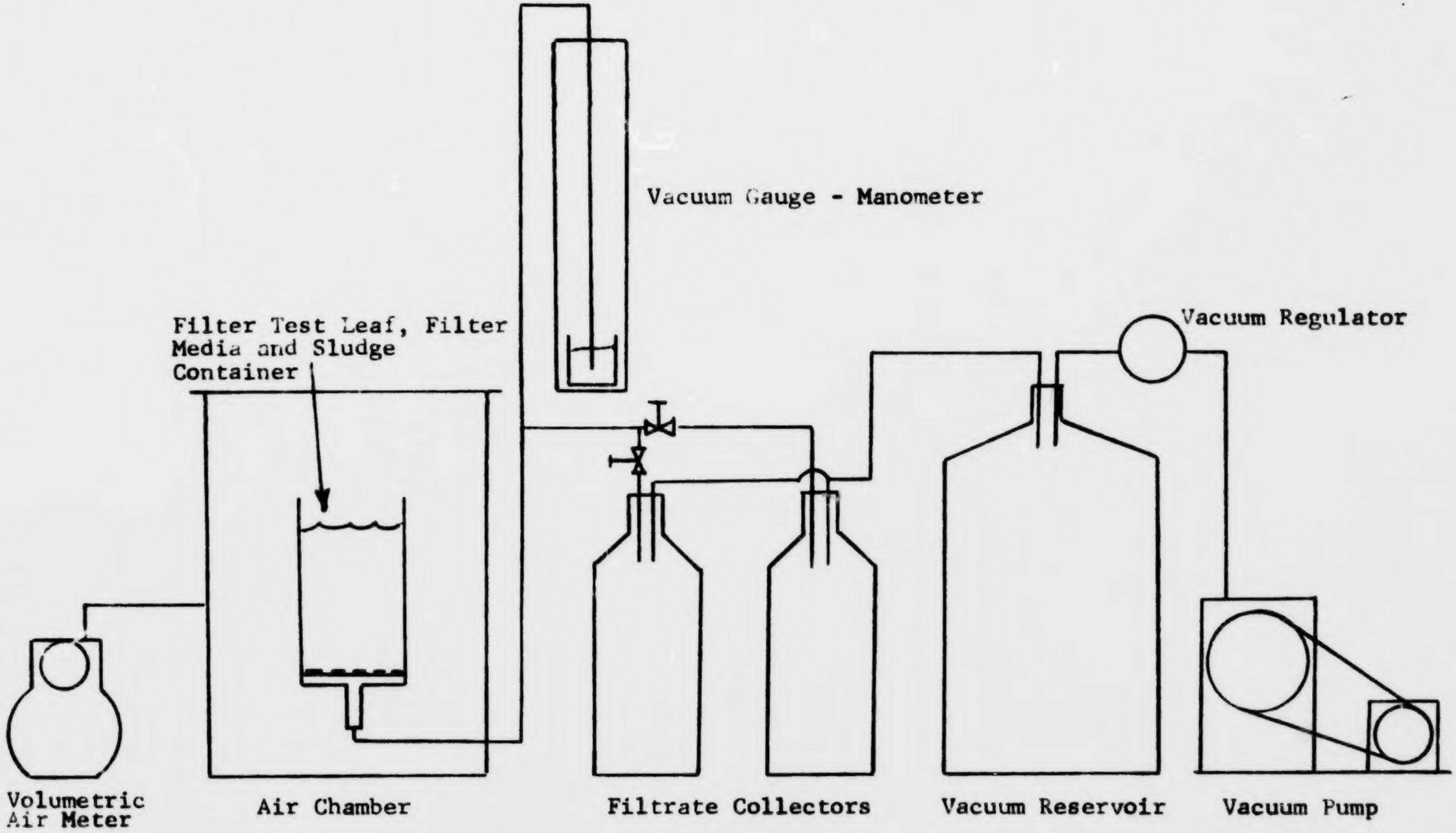
Vacuum Gauge - Manometer
Filter Test Leaf, Filter Media and Sludge Container
Vacuum Regulator
Volumetric Air Meter
Air Chamber
Filtrate Collectors
Vacuum Reservoir
Vacuum Pump

Fig. 25 VACUUM FILTER SIMULATOR FOR TOP LOADING TYPE FILTER

poured off and the filter cake was dewatered for the prescribed time.

To measure the volume of air, the filter test leaf and sludge container were enclosed in a covered container. The amount of air passing through the filter cake and the filter media was then determined by measuring the volume of air entering the container. The volume of air measured was that at atmospheric pressure because there was less than 1 in. Hg pressure drop across the air meter.

After dewatering, the filter cake was removed from the filter cloth, its average thickness and total weight determined and then dried to determine its water content and dry weight. The volume of the filtrate was then measured and observed for clarity.